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# HIGH RATE FILTRATION OF COMBINED SEWER OVERFLOWS

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27 **Abstract**

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Capital costs (ENR=1470) for a high rate filtration plant are about $23,000 per mgd. Total annual treatment costs, including capital and operating charges, range from approx. $90,000 per yr for a 25 MGD plant to approx. $390,000 for a 200 MGD treatment facility.

Principal advantages of the proposed system are: high treatment efficiencies, automated operation, and limited space requirements as compared with alternate flotation or sedimentation systems.

~~This report was submitted in fulfillment of Project #11023EYI (Contract 14-12-858) under the sponsorship of the Office of Research and Monitoring, USEPA.~~

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# HIGH RATE FILTRATION OF COMBINED SEWER OVERFLOWS

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Office of Research and Monitoring

ENVIRONMENTAL PROTECTION AGENCY

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The treatment system is comprised of a drum screen with a 40 mesh screening element (420 microns opening) followed by a deep bed, dual media, high rate filter of five feet of No. 3 Anthracite (effective size 4 mm) over three feet of No. 612 Sand (effective size 2 mm). The results show suspended solids removals of 93 percent, with polyelectrolyte addition, at a filtration rate of 24 gpm/sq ft at an average influent suspended solids of 411 mg/l. Reductions in biochemical oxygen demand averaged 65 percent.

Capital costs (ENR=1470) for a high rate filtration plant are about $23,000 per MGD. Total annual treatment costs, including capital and operating charges, range from approximately $90,000 per year for a 25 MGD plant to approximately $390,000 for a 200 MGD treatment facilities.

Principal advantages of the proposed system are: high treatment efficiencies, automated operation, and limited space requirements as compared with alternate flotation or sedimentation systems.

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# SECTION I

# CONCLUSIONS

## Characterization of Combined Sewer Overflow

Results of the sampling and analytical program of combined sewer overflows for pilot plant evaluation at the Southerly Wastewater Treatment Plant in Cleveland support the following conclusions:

1. A total of about 52 overflows a year can be expected. Most of them have a duration of 5 to 6 hours. The majority of overflows occur from rainfall having an intensity of between 0.3 and 0.5 inch per hour.

2. The concentration of suspended solids, settleable solids, BOD and COD in combined sewer overflow evidenced at the Southerly Wastewater Treatment Plant in Cleveland was as follows (July to November, 1970):

| | Suspended Solids (mg/l) | Settleable Solids (ml/l) | BOD (mg/l) | COD (mg/l) |
|---|---|---|---|---|
| Mean | 234 | 5.26 | 92 | 308 |
| Standard Deviation | 135 | 3.02 | 49 | 143 |
| Minimum | 28 | 0.2 | 16 | 57 |
| Maximum | 1560 | 19.0 | 580 | 711 |

3. The concentration of suspended solids generally reached a maximum level within 1/2 hour after the beginning of the overflow. Within 3 to 4 1/2 hours the suspended solids concentrations dropped to less than 150 mg/l.

4. Comparing combined sewer overflow and dry weather flow contaminant levels for the 1970 sampling period, average suspended solids concentration in the overflow was 25 percent higher than dry weather flow. The overflow BOD, COD and median fecal coliform levels were about 70, 80, and 30 percent, respectively of the dry weather flow.

5. For the spring sampling period (May to early June, 1971), suspended solids, BOD and COD concentrations in combined sewer overflows were 110, 30 and 20% greater than in dry weather flows, respectively.

6. From the above quality and quantity findings, the combined sewer overflow is a major pollutional source which should be considered for adequate handling or treatment.

## Evaluation of Treatment Process

Results of pilot plant testing of drum screening and high rate, deep bed, dual media filtration process at the Southerly Wastewater Treatment Plant in Cleveland support the following conclusions:

### Screening Test

1. Screening must be provided prior to high rate, deep bed, dual media filtration for longer runs, lower headlosses and efficient filtration. A drum screen with a screen size No. 40 element (equivalent to Tyler screen scale 35 mesh with 420 micron opening size and 43.6 percent open area) is most adequate and more effective for reasonable filtration operation than the corresponding No. 20 (Tyler screen scale 20 mesh with 841 micron openings) and No. 3 (Tyler screen scale 3 mesh with 6350 micron openings) screening elements.

2. The No. 40 screen was selected as the screening component. Based on composite sampling for each storm event, the full ranges of contaminant removals by this screen in combined sewer overflows were 17 to 40 percent for suspended solids; 50 to 73.5 percent for settleable solids; 4.3 to 22.2 percent for BOD and 4.5 to 41.1 percent for COD.

3. A slotted screen element, furnished by UOP Johnson Division, was evaluated. The criteria used for evaluating the slotted screen elements versus the mesh screen was the head loss and length of run in the filtration operation. The results showed that head loss in the filter columns, when preceded by the slotted screen, is in the order of four times as great as that preceded by a mesh type screen. Therefore, suspended solids removal by the slotted screen was not as effective as by the mesh type screen.

### High Rate, Deep Bed, Dual Media Filtration Results

4. Conclusions are based on sixty nine pilot filtration test runs conducted in 1970 and 1971 on combined sewer overflows utilizing the aforementioned system. Twenty one filtration test runs utilized selected polyelectrolytes, twenty nine filtration test runs evaluated combinations of coagulants (alum or ferric chloride) and polyelectrolytes on the filtration system, and nineteen were plain filtration runs.

5. Based on limited pilot test results utilizing a No. 40 mesh screen element with a high rate filtration unit, a filter media comprised of five feet of No. 3 Anthracite (effective size 4.0 mm) over three feet of No. 612 Sand (effective size 2.0 mm) was shown superior to coarser or finer media tested and this media was selected as the filtration component of the treatment system.

6. Due to variations of suspended solids concentration in combined sewer overflows, the removal efficiency of a high rate filtration system would fluctuate with the influent concentration, whereas the more important effluent concentration remained comparatively constant. Results from a typical filtration run at 8 gpm/sq ft with 30 mg/l alum and 1.0 mg/l polyelectrolyte addition are shown as follows:

| Number of Samples | Average Influent Suspended Solids (mg/l) | Average Effluent Suspended Solids (mg/l) | Removal (%) |
|---|---|---|---|
| 3 | 442 | 36 | 92.0 |
| 2 | 362 | 48 | 86.7 |
| 2 | 100 | 54 | 46.0 |

7. It was found that filtration with polyelectrolyte addition would yield better effluent quality or higher removal efficiency than plain filtration. Suspended solids influent and effluent levels and percent reductions, averaged from six samples per filter run for system operation with and without polyelectrolyte addition, are indicated as follows:

| Filtration Rate (gpm/sq ft) | Average Influent (mg/l) | Average Effluent (mg/l) | Removal (%) |
|---|---|---|---|
| Plain | | | |
| 10 | 165 | 30 | 82 |
| 16 | 175 | 37 | 79 |
| 24 | 180 | 53 | 70 |
| With Polyelectrolyte | | | |
| 8 | 400 | 8 | 98 |
| 16 | 200 | 10 | 95 |
| 24 | 250 | 18 | 93 |

8. It was found that there was no correlation between BOD removal and filtration rate. Results with 1.0 mg/l polyelectrolyte addition are shown as follows:

| Filtration Rate (gpm/sq ft ) | Average Influent (mg/l) | Average Effluent (mg/l) | Removal (%) |
|---|---|---|---|
| 8 | 67.0 | 31.3 | 57.0 |
| 16 | 67.0 | 27.0 | 59.7 |
| 24 | 67.0 | 27.5 | 60.7 |

9. Total phosphorous removal was improved with alum addition. Results of total phosphorous effluent levels and percent reductions, with and without alum addition, are shown as follows:

| Filtration Rate (gpm/sq ft ) | Average Influent (mg/l) | Average Effluent (mg/l) | Removal (%) |
|---|---|---|---|
| Without Alum | | | |
| 8 | 0.71 | 0.43 | 38.0 |
| 16 | 0.71 | 0.39 | 45.0 |
| With Alum | | | |
| 8 | 0.90 | 0.24 | 73.3 |
| 16 | 0.90 | 0.37 | 58.9 |

10. The addition of alum and polyelectrolyte to enhance process performance produced varying results in removals of suspended solids, BOD and phosphates. Process performance was determined by suspended solids removals, which ranged from 95 to 65 percent (filtration rates between 8 and 24 gpm/sq ft ).

11. It was found that the high rate filtration system was more efficient in removing inorganic (inert) suspended solids than for organic (volatile) suspended solids. As a possible extension of these results, the system would be more effective with urban runoff than for combined sewer overflows, as suspended solids in urban runoff have a higher inorganic fraction.

12. For filtration with polyelectrolyte addition, filter runs generally ranged between 4 and 16 hours, with the length of run determined by effluent quality deterioration. Head losses through the filter media ranged from 5 feet (8 gpm/sq ft ) to 30 feet (24 gpm/sq ft ).

13. Based on limited verification procedure, an inline suspended solids monitor (Model 53) furnished by Biospherics Incorporated

has shown promise in correlating results with laboratory determinations for suspended solids concentrations ranging between 30 and 240 mg/l.

Screening and High Rate Filtration Installation

14. Area requirements for full size high rate filtration plants including drum screening units, deep bed filtration units, backwashing facilities, polyelectrolyte feed facilities, and hypochlorite addition facilities (for plants in the range of 25 to 200 MGD capacity) were estimated as follows:

| Plant Capacity | Design @ 24 gpm/ sq ft (93% S.S. Removal) |
|---|---|
| 25 MGD | 3000 sq ft |
| 50 MGD | 4600 sq ft |
| 100 MGD | 9300 sq ft |
| 200 MGD | 16,500 sq ft |

15. For high rate filtration plant (s) constructed at remote outfall locations, it is apparent, from an operational and economic standpoint, that the waste backwash waters should be directed to the sanitary sewerage system for subsequent treatment at a municipal sewage treatment plant.

16. A sufficient degree of automation could be incorporated in the treatment plant so that it could operate with a minimum attendance for such items as chemical solution preparation and routine maintenance.

17. Based on pilot plant operational experience, an open, gravity type filtration system is less prone to occurrence of explosive conditions than a pressure type filter.

Cost Data

18. Capital cost data without a backwash sludge handling facility (ENR = 1470) and total annual costs, including capital and operating charges, for high rate filtration plants, in the range of 25 to 200 MGD treatment capacity, are estimated as follows (design at filtration rate of 24 gpm/sq ft):

| Plant Capacity | Capital Cost | Total Annual Cost |
|---|---|---|
| 25 MGD | $ 830,000 | $ 97,270 |
| 50 MGD | 1,312,000 | 143,000 |
| 100 MGD | 2,351,000 | 256,100 |
| 200 MGD | 3,754,600 | 388,210 |

19. Based on an average suspended solids concentration of 200 mg/l in a combined sewer overflow and a 300 hours per year operating period, solids handling and disposal costs, incurred by dry-weather sewage treatment plants in processing waste screenings and backwash solids, could range from 3 to 35 percent of the total annual cost for the combined sewer overflow filtration facility (without sludge disposal equipment).

# SECTION II

# RECOMMENDATIONS

1. A demonstration plant for the treatment of combined sewer overflows utilizing the deep bed, dual media, high rate filtration process should be engineered and constructed so that the encouraging conclusions, judgments and evaluations presented in this report can be confirmed through the operation of a full scale facility.

2. Additional pilot plant testing should be undertaken to develop a more complete system, utilizing the same unit process. By using a finer screening mesh, and possibly a finer filter media, with a more comprehensive evaluation of in-line mixing and coagulation, a more efficient and economical system may be developed.

3. A pilot plant consisting of microscreening (23 microns) and finer filter media should be evaluated to obtain a higher quality effluent. Suspended solids, in combined sewer overflow, would be removed mainly by microscreening and the dissolved and colloidal contaminants could be reduced in the filter by using proper powdered activated carbon and coagulant dosage. It is expected that the cost/benefit ratio would justify optimizing this system, since basic unit processes remain the same with only moderate increase in screen sizing. Due to the intermittent operation of a full size treatment plant (about 300 hours per year in Cleveland), the additional annual costs of activated carbon could be justified by cost-benefit considerations.

4. Define in-depth the capability and associated cost factors for sewage treatment plants to process waste solids from combined sewer overflow treatment facilities.

5. Further define, through additional pilot plant studies and engineering evaluations, the possibilities of the deep bed, dual media high rate filtration process achieving higher quality effluent levels; and also in applying this new process to other areas of water pollution control, specifically to the treatment of urban runoff, primary and secondary treated domestic sewage effluent and high solids river water (sediment control).

6. The high rate filtration process for combined sewer overflow treatment located in the area of a domestic wastewater treatment plant can be utilized for polishing the treatment, overloading or process malfunction during the majority of the time when it is not raining.

7. For a newly designed domestic wastewater treatment plant, the high rate filtration process can be adopted to handle both dry and wet weather flow (combined sewer overflow) with an adequate storage facility. This dual usage of the high rate filtration process should be considered.

8. An in-line suspended solids monitor, such as the Biospherics unit, should be further investigated. Depending on further test results, units such as this should be considered as sensing devices to enhance automation of the filtration process by providing positive control of effluent suspended solids concentrations. This monitor may also provide the important function of producing continuous and more reliable data.

9. The slotted screening element furnished by UOP Johnson Division was strong, rugged and maintenance free. Therefore, a further in-depth study of this screening element should be considered. Alternate designs of the screen should include the variation of slot opening, surface wire shape and rod location.

10. Prechlorination of combined sewer overflow prior to high rate filtration process should be further studied. Due to the advantage of the mixing effect in the filter bed, prechlorination could improve the disinfection efficiency.

11. Pilot testing should be conducted to develop mathematical relationships for a high rate filtration index or parameter to evaluate filter performance under varying storm generated influent suspended solids concentrations.

12. In designing or planning of a full size plant, an open, gravity type filter should be considered for process efficiency and operating safety. Also, a study of the high pressure pumping alternative to the filter columns should be conducted. There is a possibility of high turbulence through the pumps causing suspended solids breakdown which could affect filter performance.

13. To develop an ultimate disposal system for solid materials removed from combined sewer overflows, further study of backwash sludge characterization, such as sludge density, biodegradability, and dewatering method, should be considered.

# SECTION III

## INTRODUCTION

### General

The problem of pollution of the nation's waterways from combined sewer overflows has been well documented (1, 2). In addition to pollution from normal domestic sewage and urban runoff contaminants, combined sewer overflows also contain, in many cases, significant quantities of industrial waste. This can be evidenced by the fact that approximately 40% of the volume of waste waters currently processed in municipal sewage treatment facilities are of industrial origin (3). Effective pollution control for an area or a waterbody cannot be achieved without an adequate method or system for handling the pollutional discharges which occur from combined sewer overflows.

Recent emphasis has been placed upon developing and evaluating systems and treatment processes which will adequately cope with the combined sewer overflow problem. It is immediately evident that no matter what degree of advanced waste treatment is provided at sewage treatment facilities, water quality levels cannot be consistently maintained without controlling the highly contaminated, high volume, discharges which are experienced during combined sewer overflow conditions. Modern remedial measures generally follow three avenues: proper regulation of the sewer system to minimize overflow frequency and volumes; storage to temporarily detain this high volume, short duration discharge; and treatment of combined sewer overflows. This study and report is concerned with evaluating a new method for treating combined sewer overflow.

The nature of combined sewer overflow, that is, a highly pollutional, high volume discharge, requires a relatively high rate treatment process for economical pollution control. Deep bed, high rate filtration, a newer development in the field of industrial wastewater treatment, has demonstrated favorable cost-efficiency factors when dealing with high volume wastewater discharges, especially where suspended solids comprise one of the principal contaminants (4, 5). Thus, it was felt that such a process, which currently has significant applicability and usage in the steel industry, might provide an effective and efficient solution to the treatment of combined sewer overflows.

To evaluate the applicability and effectiveness of the high rate filtration process in removing contaminants from combined sewer overflows, a testing program was undertaken at Cleveland's Southerly Wastewater Treatment Plant. The City of Cleveland ranks seventh in the nation in total area served by combined sewers (44,000 acres), and is fourth in population served by combined sewer systems (1,000,000 persons) (2). As can be expected, Cleveland has a very serious problem of combined sewer overflows.

## Scope of Project

The development and demonstration project at Cleveland's Southerly Wastewater Treatment Plant evaluated deep bed, high rate dual media filtration for treating the combined sewer overflows experienced at this sewage treatment plant. The project essentially covered three areas: first, engineering and construction of a pilot plant; second, testing the efficiency and effectiveness of the high rate filtration process in removing combined sewer overflow contaminants; and lastly, data evaluation and design of representative treatment units with associated cost estimates.

The field testing, sampling and evaluation program was conducted in 1970, and again in 1971. The 1970 test work spanned from July through November and essentially established the feasibility of the filtration concept and also the essentially components of the proposed treatment system. The 1971 field test work spanned from May through August and was substantially comprised of optimizing the performance of the proposed system via the addition of various polyelectrolytes and coagulants prior to filtration.

Two additional tasks, not specifically related to combined sewer overflow, were incorporated into the overall study. The first task was comprised of a preliminary field test program evaluating deep bed, high rate filtration as a treatment method for secondary sewage effluent from activated sludge plants. The second, somewhat unrelated project task, included an evaluation of a suspended solids effluent monitoring system. Both of these project tasks are described and reported in independent sections contained in the appendices of this report.

## The Cleveland Situation

As indicated, the pilot test facility evaluating the applicability of the high rate filtration process was located at the Southerly Wastewater Treatment Plant, which receives flow from the Southerly Sewerage

District of Cleveland. The Southerly District, as shown in Figure 1, consists of residential, commercial and industrial areas, encompassing roughly half of the metropolitan region, both in population as well as land area. This district also includes many of the large industrial plants located within the greater Cleveland area. Based on preliminary 1970 Census data, the Southerly District is estimated to have 600,000 people of the 1,300,000 residing in the Greater Cleveland vicinity. The Southerly District covers approximately 62,000 acres.

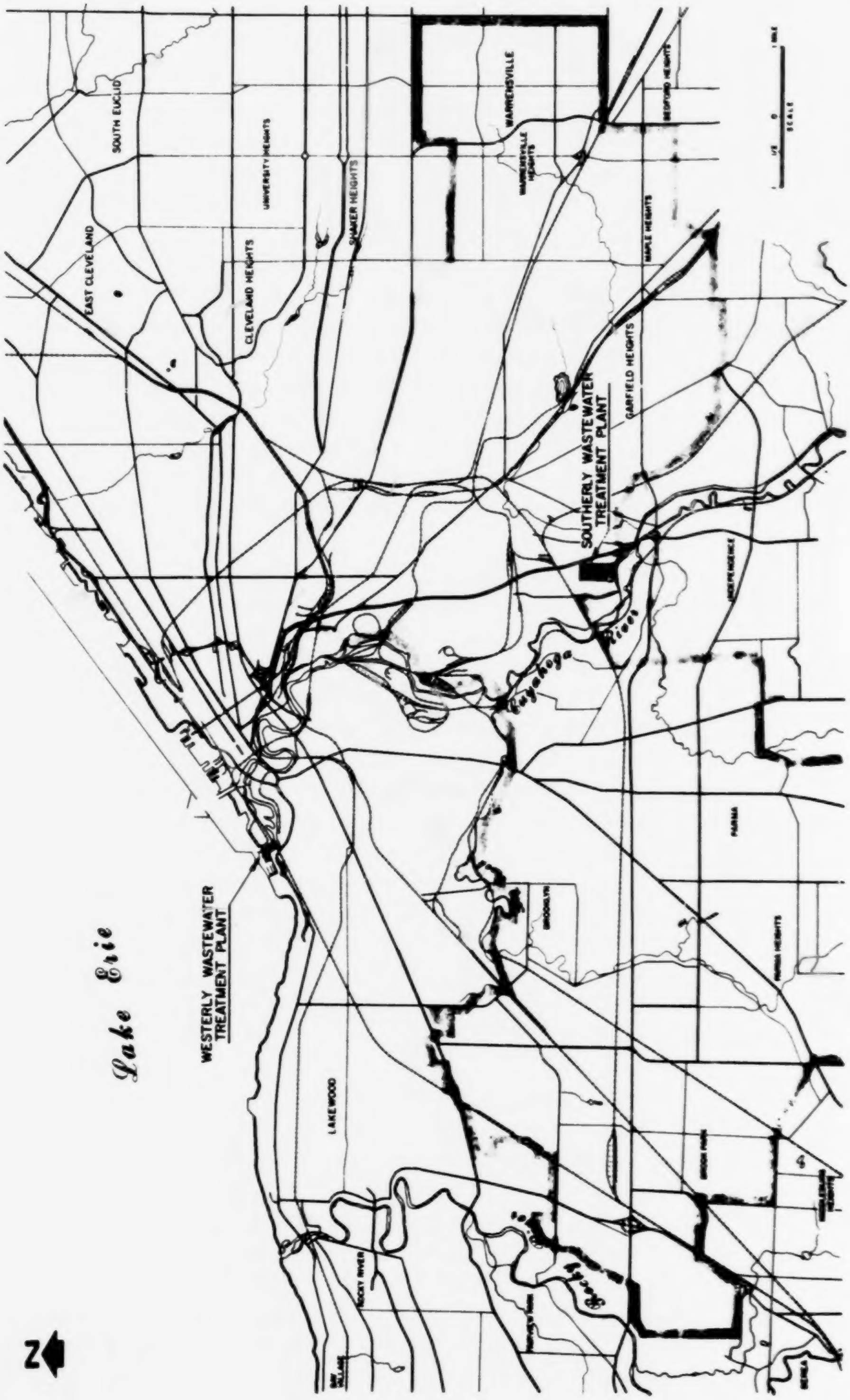
Generally speaking, the Southerly district is served by a combined sewer system and all discharges, including sanitary sewage, industrial wastewater and urban runoff are conveyed by the system. Considerable portions of the combined sewer system are believed to have been built over fifty years ago. Most of the new suburban areas within the district are provided with separate sewer systems. However, it is reported that numerous cross connections between sanitary sewers and storm sewers do exist within these suburban communities.

Precipitation in the study area averages between 30 and 36 inches a year. The monthly average ranges from 1 to 6 inches, with the greatest precipitation evidenced in the spring months. It is reported that the study area is subject to frequent low intensity rainfalls which will account for most of the annual runoff in the area.

The combined sewer overflow problem in the study vicinity is an extremely complicated one. Based on available information, there are over 600 overflow structures within the district. The normal dry weather flow to the Southerly Wastewater Treatment Plant is 80 million gallons per day, whereas the hydraulic capacity through the plant is in the range of 160 million gallons per day. It is estimated that the wet weather flow in the study area is in the range of two to ten times the dry weather flow, and causes a substantial discharge of combined sewer overflow to the Cuyahoga River and to Lake Erie (6).

## Essentials of High Rate Filtration

The history of water filtration began with the use of slow sand filters to clarify drinking water. These were beds of granular material, arranged in various acreages, which were doused with the water to be filtered. The water was collected after percolating through several feet of the filter bed. Usual rates of filtration were in the order of 0.02 to 0.2 gpm/sq ft. The development of the rapid sand filtration process occurred before 1900. This process requires the prior application of



SOUTHERLY WASTEWATER TREATMENT PLANT LOCATION PLAN

FIGURE I

chemicals to effect coagulation. The water is then passed through clarification tanks where most of the floc formed is settled out prior to filtration. These improved filters provided good water at filtering rates of 2 gallons per minute per square foot. However, of even greater significance was the fact that they could be cleaned mechanically without removing the media from the bed. Much recent attention and test work in potable water filtration has been given to the feasibility of filtering at higher rates, up to 10 gallons a minute per square foot (7).

The general practice of industrial wastewater filtration first emerged in Europe where the supply of water for industrial purposes became limited. The industrial wastewater filters in Europe were designed to operate in the general range of 6 to 10 gallons per minute per square foot. These units were designed to provide reliable treatment for many years without any great maintenance effort.

Ultra high rate filtration under study for the treatment of combined sewer overflow, is similar to the industrial type filtration in Europe except that two layers of media of different composition are used (5). Together, they form a filter bed that is much deeper than used previously (7 feet or more). By using dual media, high capacity filter bottoms and special backwashing facilities, the rate of filtration of wastewater has been increased greatly.

One of the essential differences between a deep bed, dual media, high rate filter and its counterpart for potable water treatment is that the deep bed filter is designed to accept appreciable solids loadings, on the order of many hundreds of milligrams per liter. To be most effective, filtration through media that are graded from coarse to fine in the direction of filtration is desirable. A single medium filter cannot conform to this principle since backwashing of the bed automatically grades the bed from coarse to fine in the direction of washing; however, the concept can be approached by using a two layer bed. A typical case is the use of coarse anthracite particles on top of less coarse sand. Since anthracite is less dense than sand, it can be coarse and still remain on top of the bed after the backwash operation. Another alternate to achieve filtration through coarse to fine media would be an upflow filter. But these units have limitations in that they cannot accept high filtration rates.

Over the past few decades, many theories have been promoted to describe the manner and mechanism by which suspended matter is entrapped within a filter. Tchobanoglous (8) has categorized filter removal mechanisms into nine areas, which include straining, sedimentation, inertial impaction, interception, chemical adsorption, physical adsorption, adhesion and adhesion forces, coagulation-flocculation, and biological growth. Just how suspended matter is intercepted in depth rather than at the surface of a high rate filter, and which mechanism are principally involved, is not yet fully understood. However, it is presently surmised that due to the longer depth of travel through the media, the mechanisms contributing to the removal of suspended material within the filter have a greater change to be effective (9).

The principal parameters to be evaluated in selecting a high rate filtration system are media size, media depth and filtration rate. Since much of the removal of solids from the water takes place within filter media, their structure and composition is of major importance. Too fine a media may produce a high quality effluent but also may cause excessive head losses and extremely short filter runs. On the other hand media that is too coarse may fail to produce the desired clarity of the effluent. Therefore, the selection of media for high rate filtration is made by pilot testing using various materials in different proportions and at different flow rates. Depth of media is limited by head loss and backwash considerations. The deeper the bed, the greater the head loss and the harder it is to clean. On the other hand, the media should be of sufficient depth so as to be able to retain the removed solids within the depth of the media for the duration of filter run at the design rate without permitting a breakthrough. A deeper bed also affords greater opportunity for interplay of the various forces which are generated within the filter bed.

The design filtration rate must be such that the effluent will be of a desired quality without causing excessive head loss through the filter, which in turn requires frequent backwashing. At high filtration rates, shear forces seem to have significant effect on solids retention and removal in a high rate filter. Recent experience at a high rate filtration facility treating industrial waste water seem to reinforce this theory, as winter performance of the filtration facility (without chemicals) was poorer than summer performance, when water viscosities are lower due to higher water temperatures (10). Polyelectrolyte addition was required during cold water operating conditions (winter) to maintain required effluent quality. The addition of polyelectrolyte, and/or coagulants prior to filtration can have a significant effect on process efficiency.

# SECTION IV

# PILOT PLANT FACILITIES

## Process Units

An overall schematic of the pilot plant is shown in Figure 2. The major elements of the treatment system are a screening facility and a deep bed, high rate dual media filter. As indicated on this drawing, two storage tanks, 5000 gallons each, equipped with mixers, were provided between the screen and the filters. The purpose of these tanks was to provide sufficient combined sewer overflow storage to allow extended filtration test runs.

Briefly, the combined sewer overflow was lifted from the Southerly Wastewater Treatment Plant junction chamber and passed through a drum type screening unit. The effluent from the screen flowed by gravity into the two storage tanks. Water from the storage tanks was then pumped into the filtration test columns.

Four filtration pilot columns were located in the test setup. Three of the pilot columns were 6-inch diameter plexiglass tubes, while the fourth was one foot square. All of the pilot columns were of sufficient size to provide reliable removal data in regard to the filtration process. The larger unit gave a better indication of the effect of backwashing on the filtration media, as "wall effects" were evidenced in the smaller test units during backwashing. Three chemical feeding systems were included in the pilot plant installation.

In addition, for the 1971 test work, a coagulant-testing apparatus was incorporated into the pilot plant equipment. This apparatus, as shown in Figure 3, was comprised of six 3-inch diameter lucite filter columns with associated chemical feeding equipment. The coagulant testing apparatus permitted simultaneous comparison of the effect and efficiency of trying various coagulants, and polyelectrolytes, at various dosages, to the filter influent to improve process performance. Selected coagulants, polyelectrolytes, and dosages were then utilized in the pilot columns, from which operational data was obtained (length of run, head loss, etc.).

The flow volumes through each filtration column were controlled by observing a flow meter and regulating a valve on the effluent from the filter. Pressure gauges were located along the height of the pilot filtration column to profile head losses throughout the filter depth. A

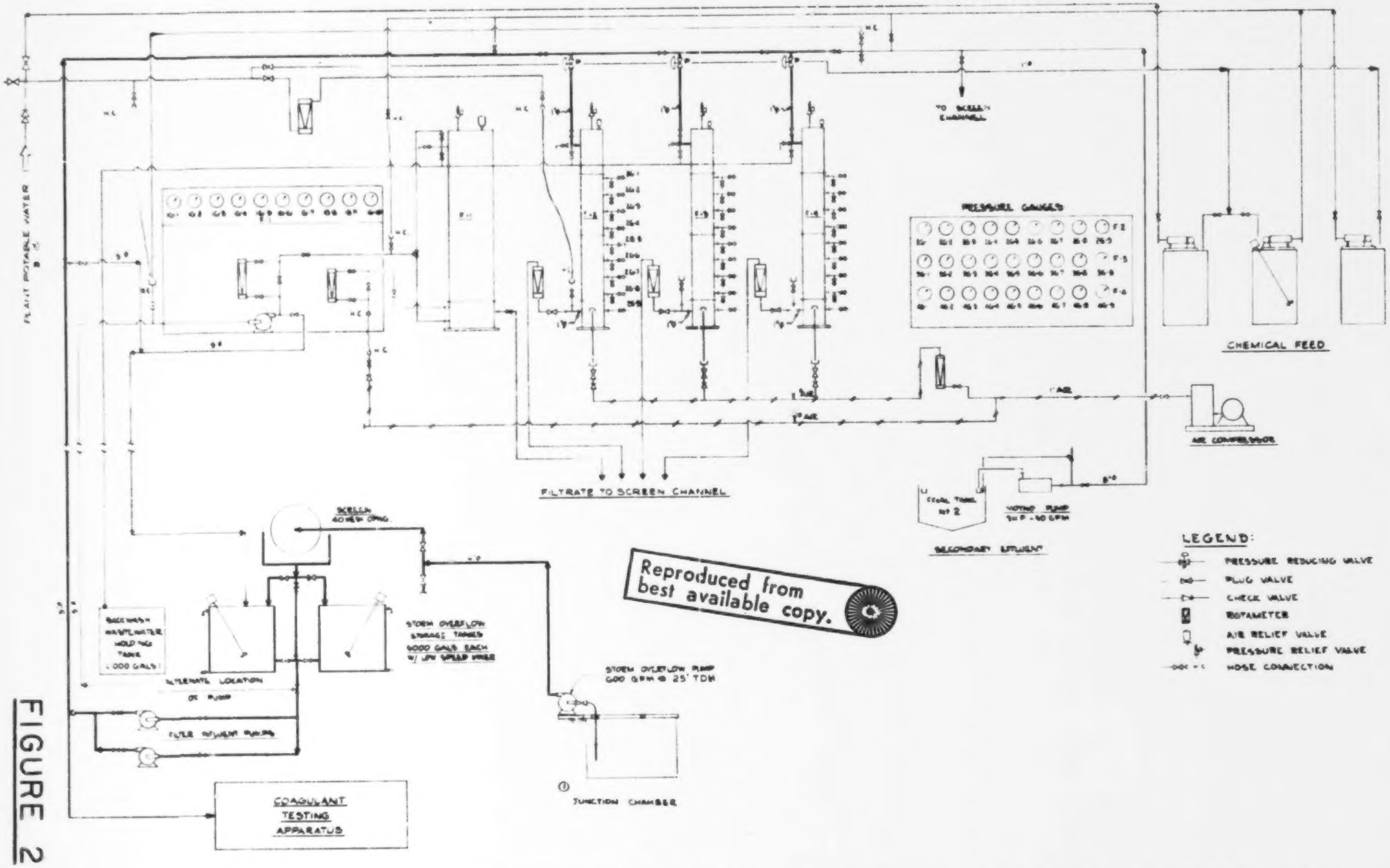


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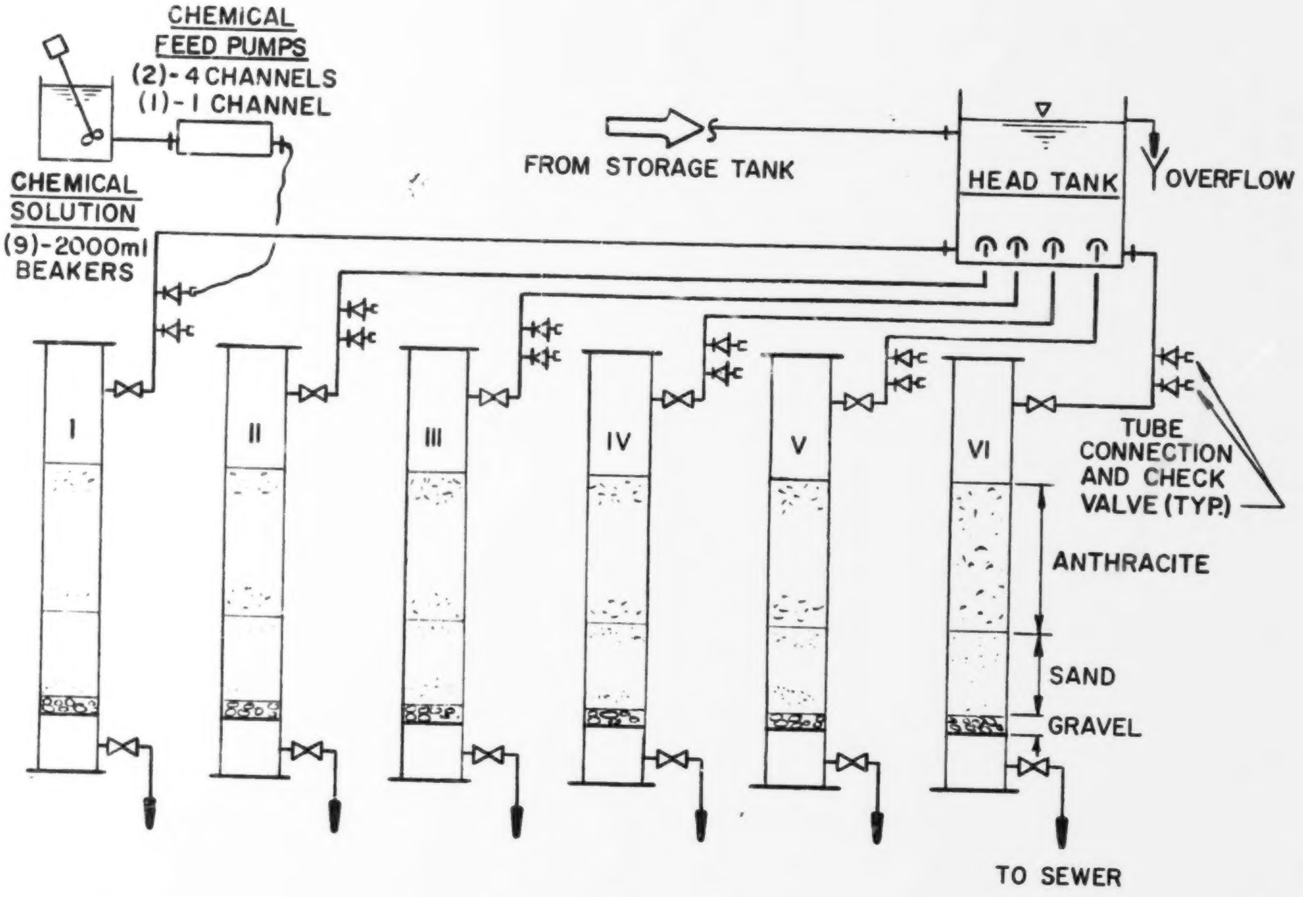
FIGURE 2

HIGH RATE FILTRATION PILOT PLANT FLOW DIAGRAM



COAGULANT TESTING APPARATUS SCHEMATIC DIAGRAM

FIGURE 3

small compressor was included at the test installation to provide a source of air for backwashing the filter columns. Backwash water was obtained from the existing service water system at the Southerly Wastewater Treatment Plant.

Preliminary testing of secondary effluent was accomplished at the pilot test setup, as indicated on the schematic drawing. Wastewater was collected in a launder of a secondary sedimentation tank, and pumped via hose to the test site and to the filter columns.

Major equipment at the pilot plant included the following:

1. Combined Sewer Overflow Pump - self-priming centrifugal pump, manufactured by Barnes Manufacturing Company, Model 105 C-E, with cast iron body and cast iron open type impeller with six inch suction and six inch discharge. The pump was driven by a 1200 rpm, 10 HP TEFC motor, operating at 230/460 volts. The pump and motor were mounted integrally on a base plate.

2. Drum Screen - A continuous duty, gravity flow, self-cleaning straining system manufactured by Zurn Industries, Inc. The heart of the screen was a rotating drum type straining element enveloped with replaceable wire mesh plate (4'-0" diameter x1'-0" long). Rotating on its horizontal axis, the straining elements accepted incoming gravity flow while partially submerged inside an open chamber. A jet spray washed off, debris trapped on the mesh as the drum turns, into an elongated waste collector located inside the element but above the fluid level. The wastewater was then discharged into a drainage line.

3. Pilot Filter Columns - Three six inch diameter filter columns - The filter columns were made of transparent plexiglass tubing having an outside diameter of seven inches and 3/8" wall thickness. Each filter was seventeen feet high and consisted of four sections. The four sections were connected by flanges using 1/4 inch bolts. Nine pressure taps, eighteen inches apart were provided along the column for measuring head loss development during filtration. Filter media was supported by a plexiglass plate with a plexiglass nozzle. Above the plate, an eighteen inch gravel layer was provided to support the filter media. A rotameter and valve were installed at the filter discharge end for measuring and controlling the rate of flow. One filter column - supplied by De Laval Turbine, Inc. The filter column was 12 inches by 12 inches in cross section and had a nominal height of 18 feet. Three sides of the column were made of steel plate and the front side was made of transparent plexiglass plate. Nine pressure taps, twelve inches apart, were provided along the

column for pressure measurement. Filtration rate was controlled by a rotameter and gate valve on the filter effluent line.

4. Backwash Air Compressor - The air compressor was Model A490K8 - 103-80, oil free type, manufactured by Corkem Pump Company. The compressor was mounted on an 80 gallon receiver, ASME Code 200 psig working pressure. The unit was complete with pressure gage, intake filter, hydrostatic relief valve and constant speed unloaders. The compressor was driven by a 2 HP drip proof 1750 rpm motor operating at 230/460 volts.

5. Chemical Feed Systems - Each system consisting of a metering pump, mechanical mixer and a chemical solution tank. The metering pumps were positive displacement, diaphragm type, with plastic end. The pumps were driven by 1/4 HP, single-phase capacitor-start motors. The chemical solution tanks were epoxy lined steel, each having a capacity of 55 gallons and equipped with a cover. The mixers were driven by 1/4 HP totally enclosed motors. The mixers have rubber covered shafts and impellers. The pumps, chemical solution tanks and mixers were supplied by Wallace and Tiernan, Inc.

6. Steel Tanks

a. Combined Sewer Overflow Storage Tanks

Two 5,000 gallon steel tanks were provided for storing incoming combined sewer overflows. Each tank was made of carbon steel plate and equipped with overflow, outlet and drain connections. An agitator was provided for preventing solids settlement in the tank. The agitator was driven by a 3 HP totally enclosed motor, operating on 230/460 volt, 3 phase, 60 cycle current. The motor is integrally mounted on a gear reduction unit providing an agitator shaft speed of 350 rpm. The agitator was manufactured by Lightnin Mixing Equipment Company. The two tanks had a total capacity of 10,000 gallons providing approximately 7 and 4 hours detention time at 16 gpm/sq ft and 24 gpm/sq ft flux rate, respectively, with the four filter columns in operation.

b. Backwash Effluent Storage Tank

One 1,000 gallon steel tank was used as the filter backwash effluent storage tank. The tank was made of carbon steel plate and equipped with outlet and drain connections.

### 7. Coagulant - Testing Apparatus

#### a. Head Tank

To distribute flow to the six filter columns - an eighteen inch diameter three foot long, transparent plexiglass tube was used as filter influent head tank. Overflow nozzles were equipped to provide a constant head for filter influent flow.

#### b. Filter Columns

Six filter columns, made of three-inch diameter transparent plexiglass tubing, were installed at the pilot plant site. Each filter column was eighteen feet high and consisted of three sections. The three sections were connected by two Victualic couplings.

#### c. Chemical Feed System

Three peristalic pumps were installed. Two units provide four channels each and one unit had one channel. The pumps were capable of feeding nine different chemicals at the same time.

8. Secondary Effluent Pump - A positive displacement self-priming pump was used for delivering secondary effluent to filtration testing site. The pump was manufactured by Moyno Pump Division, Robbins and Myers, Inc., Frame SWG 8 - Type CDQ. The unit was mounted on structural steel "L" type base plate and driven by "V" belts and pulleys covered by suitable belt guard (450 rpm). The pump was driven by a 3 HP TEFC motor, operating on 3 phase, 60 cycles, 230/460 volt current.

## Test Site

The pilot plant for testing the applicability of high rate filtration for the treatment of combined sewer overflows was located at the Screen Building of the Southerly Wastewater Treatment Plant. This Plant utilizes the activated sludge process for the treatment of sanitary and industrial waste flows from the Cleveland vicinity. The nature of the plant waste is somewhat unique in that the industrial contribution is very large, as evidenced by the low BOD/COD ratio of approximately 0.3. The dry weather flow to the plant can, therefore, be described as representative of an urban area with a heavy industralized concentration.

The average dry weather flow to the Southerly Plant is in the order of 80 million gallons per day. Under storm conditions, the plant can accept 160 MGD through its primary facilities. The Southerly Wastewater Treatment Plant effects approximately 87 percent removal of suspended solids and 90 percent removal of biochemical oxygen demand. Plant effluent quality levels are generally in the range of 26 mg/l suspended solids and 16 mg/l biochemical oxygen demand, as shown in Table 1.

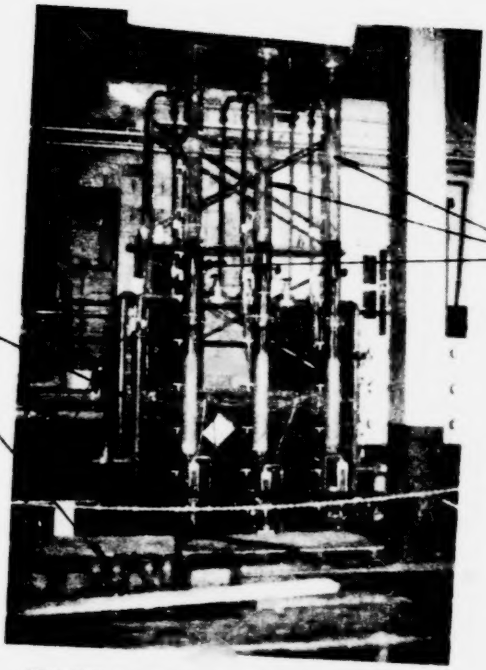
The pilot plant influent pump, screening facility, and storage tanks were located outdoors adjacent to the Screening Building, as shown in Figure 4. The filtration test columns, associated backwashing and chemical feed equipment, coagulant-testing apparatus and a small laboratory and storage room, were located inside the Screen Building. Figure 5 shows the location of the pilot plant inside the Southerly Wastewater Treatment Plant.

Table 1

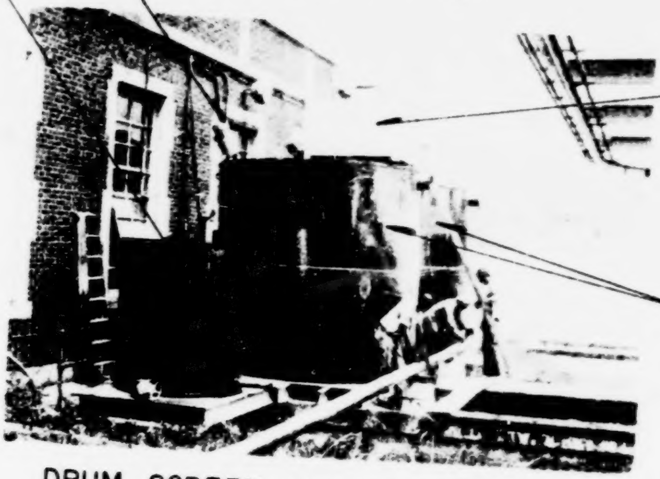
## SOUTHERLY WASTEWATER TREATMENT PLANT EFFLUENT QUALITY*
## CLEVELAND, OHIO (APRIL 1969 - FEBRUARY 1970)

| | Suspended Solids | | | | B.O.D. | | | |
|---|---|---|---|---|---|---|---|---|
| | Plant Effluent (mg/l) | | | Removal | Plant Effluent (mg/l) | | | Removal |
| Month | Average | Minimum | Maximum | (%) | Average | Minimum | Maximum | (%) |
| April | 20 | 4 | 44 | 86 | 16 | 2 | 26 | 84 |
| May | 20 | 2 | 62 | 88 | 16 | 7 | 25 | 83 |
| June | 21 | 7 | 59 | 90 | 12 | 5 | 19 | 92 |
| July | 10 | 3 | 34 | 95 | 10 | 7 | 16 | 92 |
| August | 15 | 2 | 32 | 94 | 13 | 7 | 20 | 90 |
| September | 25 | 2 | 91 | 84 | 17 | 7 | 30 | 90 |
| October | 33 | 2 | 130 | 85 | 12 | 4 | 20 | 93 |
| November | 27 | 2 | 61 | 85 | 16 | 5 | 24 | 89 |
| December | 40 | 3 | 97 | 85 | 15 | 7 | 26 | 90 |
| January | 37 | 2 | 104 | 82 | 20 | 10 | 30 | 87 |
| February | 44 | 2 | 100 | 80 | 28 | 13 | 55 | 80 |

* Data from Southerly Wastewater Treatment Plant Process Department

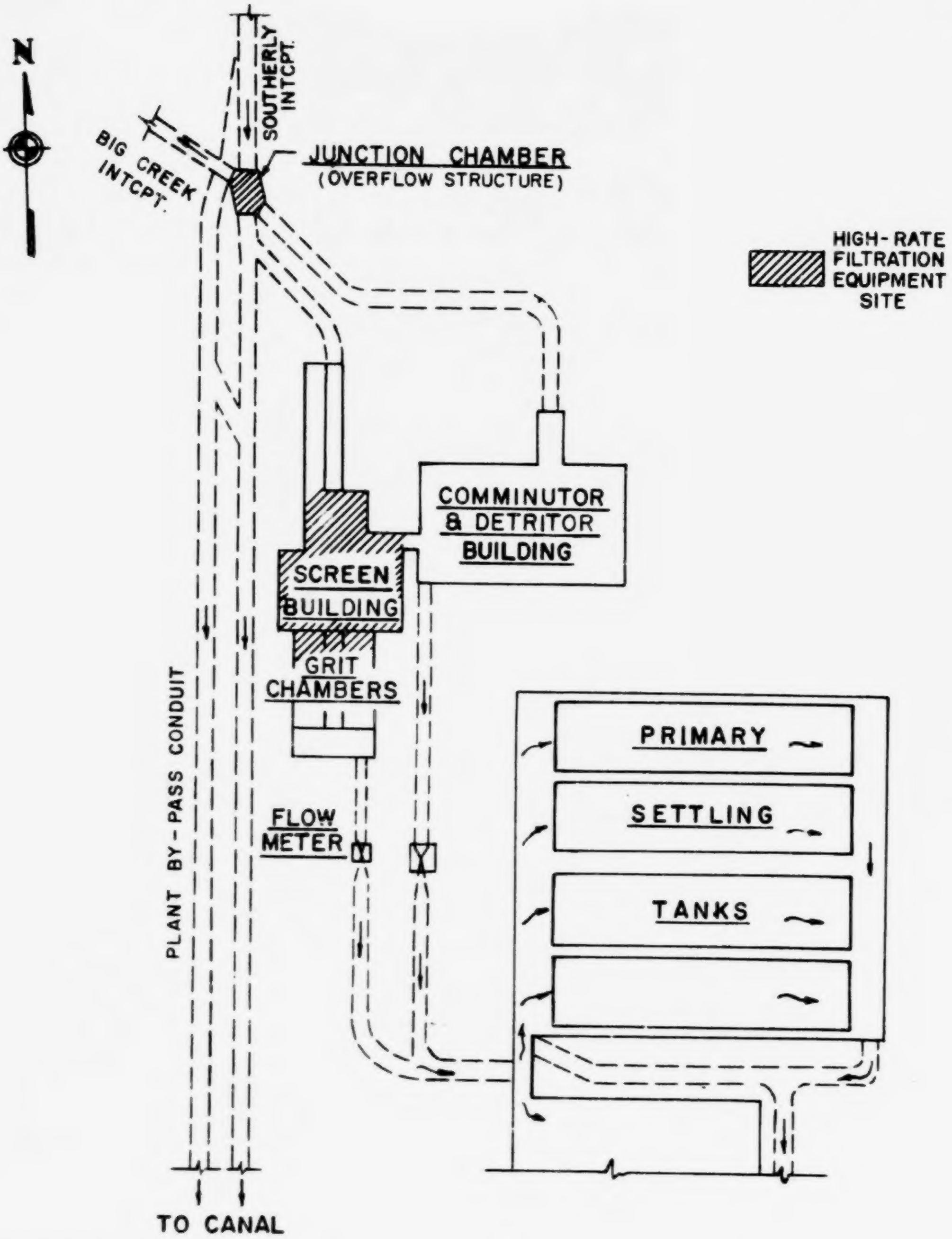


FILTER TEST COLUMNS
(Inside building)



DRUM SCREEN AND STORAGE TANKS
(Outside)

PILOT PLANT FACILITIES FIGURE 4



FILTRATION PILOT PLANT LOCATION PLAN

FIGURE 5

# SECTION V

# TESTING PROGRAM

## Parameters

Two distinct types of test parameters were utilized and evaluated during this study. The first type of parameter can be called or described as design parameters, as they relate to the major features and unit sizes of any proposed treatment system. The second type can be described as water quality parameters, which are essentially contaminant levels in and out of the treatment process.

The two major process units or equipment units in the proposed treatment system are the drum screen and the deep bed, high rate filter. Construction of a full scale treatment plant employing the process sequence under study would require design parameters for the screen and for the filtration process. The major criteria for the screen are screen type, screen mesh opening and hydraulic loading.

Numerous studies have been performed on various screen types and screen mesh openings to evaluate their efficiency in reducing combined sewer overflow pollutants. The intention and major emphasis of this program was not to determine the optimum removal characteristics that can be obtained from a particular screen, but to select a screen of sufficient durability and with sufficient removal properties that would permit the filtration process to operate in an efficient and effective manner. Thus, in selecting and operating the screening facility, Hydrotechnic relied to a great extent on past experience and minimized the number of variables that were changed throughout the test program.

The filtration system, which is the heart of the overall process sequence, can be characterized and described by the following parameters:

Media composition
Media depth
Filtration rate
Coagulant addition
Length of filter run
Head loss
Backwash water volume
Backwash procedure

A definition of these elements allows the construction of a full scale facility.

Water quality parameters or analyses utilized after agreement with the EPA Project Officer, are those normally associated with combined sewer overflows. Principal emphasis was given to the following analyses:

Total Suspended Solids
Settleable Solids
Biochemical Oxygen Demand
Total Phosphate
Chemical Oxygen Demand

Other water quality analyses were also performed, both to provide a detailed gravity profile of the combined sewer overflow, and also to provide information as to process performance on a wide range of wastewater contaminants. Table 2 is a complete listing of all water quality analyses utilized (11, 12).

Total organic carbon analyses were performed on filter influent and effluent samples after an automatic analyzer was installed by Hydrotechnic and EPA at the Southerly Wastewater Treatment Plant. Turbidity, settleable solids and temperature were determined at the test site. The bulk of the laboratory analyses were performed by local commercial laboratories in Cleveland.

These water quality parameters can be used to determine the effectiveness of the treatment process under study in reducing combined sewer overflow contaminants. The major water quality parameter for determining the effectiveness of the treatment process, since the proposed filtration process is essentially a solids removal process, is suspended solids. Insoluble BOD, simultaneously removed along with suspended solids, and soluble (ionizable) phosphates, rendered removable by the addition of coagulants, are also significant water quality parameters.

## Program Scope

The testing program at the Southerly Wastewater Treatment Plant for combined sewage storm overflows can be viewed as three separate operations. The first is the characterization of the combined sewer overflows. This consisted of sampling combined sewer overflows and analyzing samples collected for appropriate water quality parameters.

Table 2

WATER QUALITY ANALYSES

| Analysis | Method Used |
|---|---|
| **Solids** | |
| Suspended Solids (SS) | Filtered through glass fiber filter (pore size 0.8 micron) and dried at 103-105°C. |
| Volatile Suspended Solids (VSS) | Filtered and ignited at 550°C. |
| Total Solids (TS) | Evaporated to dryness at 103-105°C. |
| Total Volatile Solids (TVS) | Evaporated and ignited at 550°C. |
| Settleable Solids (Set.S.) | Imhoff cone, by ml/l. |
| **Organic** | |
| Biochemical Oxygen Demand (BOD). | Unblended, diluted and incubated for 5 days at 20°C. |
| Chemical Oxygen Demand (COD). | Oxidized by $K_2Cr_2O_7$ solution. |
| Total Organic Carbon (TOC). | Dow-Beckman Carbonaceous Analyzer. |
| **Nutritional** | |
| Total Phosphate ($TPO_4$) | $H_2SO_4$ hydrolysis and colorimetry. |
| Soluble Phosphate (Sol.$PO_4$) | Filtration, hydrolysis and colorimetry. |
| Total Kjeldahl Nitrogen (TKN) | Kjeldahl digestion. |
| **Bacteriological** | |
| Total Coliforms | Membrane Filter (pore size 0.45 micron). |
| Fecal Coliforms | Membrane Filter (pore size 0.45 micron). |
| Fecal Streptococcus | Membrane Filter (pore size 0.45 micron). |
| **Other** | |
| Oil and Grease | Liquid-liquid extraction. |
| pH | Electrometric Measurement. |
| Temperature | Thermometer. |
| Turbidity | Hach Colorimeter, Range 0-500 JTU (Jackson Turbidity Units - Formazin Standard). |

The second and third operation involved the proposed treatment process and was essentially comprised of two individual treatment components, a screening facility and the filtration facility. Each of these can be viewed as a separate study, although they are, of necessity, interrelated in terms of the overall treatment process and treatment efficiency.

## Characterization of Combined Sewer Overflow

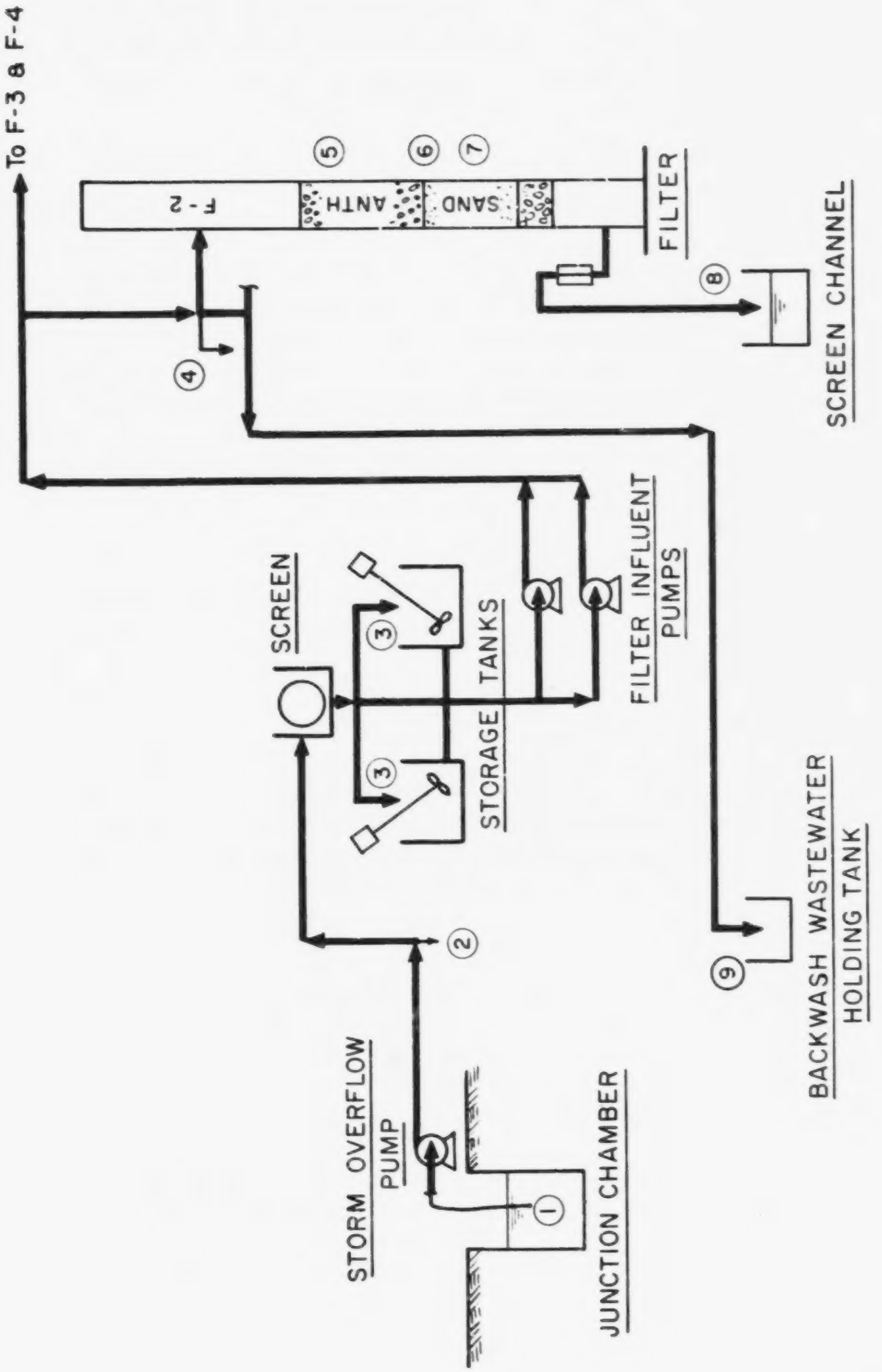
Characterization of combined sewer overflows occurring at the influent junction chamber of the Southerly Wastewater Treatment Plant was performed for fifteen storms, thirteen occurring during 1970 and two occurring during 1971. Figure 6 shows the location of sampling points for the test project at Cleveland. Sampling point #1 is the combined sewer overflow characteristic sampling point. Samples were collected manually.

A test was initiated, and combined sewer overflow characterization sampling would begin after an observation of rainfall or reported rainfall within the Cleveland area. The plant flow meter would be scrutinized, and when the flow rose above approximately 100- 110 MGD (normal dry weather flow of approximately 80 MGD) sampling would commence. Samples were collected at 5 minute intervals for the first 30 minutes, and at 30 minute intervals for the next 90 minutes, and at one hour intervals for the duration of the combined sewage storm overflow. This was generally determined by monitoring the Southerly Wastewater Treatment Plant influent flow meter, and when the plant flow dropped below approximately 90-100 MGD, it was assumed that the combined sewer overflow conditions had stopped.

## Screening

The screen type used for almost the entire duration of the test work at Cleveland was a mesh type screen. All system data and filtration data was obtained utilizing a mesh screen.

The mesh screen tested included: No. 3, No. 20 and No. 40 mesh screen. The characteristics of the three screen meshes tested are:



SAMPLING POINT LOCATION SCHEMATIC DIAGRAM

FIGURE 6

| Mesh Screen Designation | Screen Opening (microns) | (inches) | Tyler Screen Scale Equivalent (mesh) | Open Area ( % ) |
|---|---|---|---|---|
| No. 3 | 6350 | 0.250 | 3 | 57.6 |
| No. 20 | 841 | 0.0331 | 20 | 43.6 |
| No. 40 | 420 | 0.0165 | 35 | 43.6 |

At the end of the 1971 test work, a series of tests were performed on a slotted type screen to see if it could provide the necessary removals to permit an efficient operation. The intention and reason for evaluating the slotted type screen was because of its sturdy construction. This testing was accomplished simply by replacing the mesh element on the rotating drum screen with panels of slotted screen which were furnished by the Johnson Division of UOP. Two slot screen types were tested, as follows:

| Slot Opening (microns) | (inches) | Tyler Screen Scale Equivalent (mesh) | Open Area ( % ) |
|---|---|---|---|
| 200 | .008 | 65 | 12 |
| 400 | .016 | 35 | 21.1 |

Referring to Figure 6, sampling points #2 and #3 were assigned to the screening unit. Influent and effluent samples were collected at 30 minute intervals for the first 2 hours of the combined sewer overflow and at one hour intervals thereafter, until the duration of the combined sewer overflow had ended.

The effluent from the screening unit was directed to two 5,000 gallon storage tanks, which served as storage reservoirs for conducting filtration tests.

## Deep Bed, High Rate Filtration

The testing program evaluating the filtration components of the proposed system was conducted primarily in two phases. First, evaluation and selection of system media and filtration rates, and secondly, optimization of the filtration process via coagulants and polyelectrolyte addition prior to filtration.

Filtration media evaluated included: four or five feet of anthracite over three feet of sand. The characteristics of the media are indicated as follows:

| Media | Effective Size | Uniformity Coefficient |
|---|---|---|
| No. 4 Anthracite | 7.15 mm. | 1.42 |
| No. 3 Anthracite | 4.0 mm. | 1.5 |
| No. 2 Anthracite | 1.78 mm. | 1.63 |
| No. 612 Sand | 2.0 mm. | 1.32 |
| No. 48 Sand | 3.15 mm. | 1.27 |

Media selection was accomplished in the pilot test apparatus (see Figure 6). Referring to this figure, the two key points in the filtration system were sampling points #4 and #8. Sampling point #4 was at the influent of the filter columns and sampling point #8 was the filtration column effluent. Sampling points # 5, 6 and 7 were intermediate sampling points along the filtration media depth. It was anticipated that data obtained from samples at these levels would give an in-depth picture of which areas of the filter performed the major portion of the suspended solids removal. Influent and effluent samples (points #4 and #8) were taken at thirty minutes, one hour, and at hourly intervals thereafter.

Sampling point #9 was at the backwash effluent. Samples of backwash effluent provided information as to the nature of the backwash flow, both on an instantaneous and composite basis. Backwash effluent samples, when viewed in conjunction with a particular backwash procedure, can be used as a guide to the effectiveness of filter cleaning.

The filtration columns were run from 6 to 12 hours, depending upon head loss and effluent quality. The storage tanks provided sufficient capacity for extended filter runs.

As indicated in the previous section, the samples collected during the testing program were analyzed for appropriate wastewater contaminants. Head loss measurements were taken at each filter column by reading the various pressure gauges located along the depth of the filtration media at one hour intervals, or more frequently. These readings can be used to identify and define the energy expended by the flow in overcoming friction during the filtration run.

The filter columns were backwashed by using low pressure air followed by water. Initially, after the filtration run had terminated, the columns were backwashed by low pressure air at approximately 15 scfm per sq ft for about 2 minutes. The air was then turned off, and water introduced at a rate of 25 to 75 gpm per square foot, for 5 to 10 minutes. A rate of 30 gpm/sq ft appears to be sufficient for backwashing. Samples of the backwash effluent (sampling point #9) were collected. Both composite and grab sampling methods have been utilized. Composite samples give an indication of the total amount of material removed in the filter backwash, and grab samples define the pattern and the peaks of backwash solids concentration.

For the coagulant-testing apparatus which was utilized to select optimum coagulants and polyelectrolytes and appropriate dosages to be applied prior to filtration, samples were collected at hourly intervals for three hours. These samples were composited over a ten-minute interval at each hour. A typical test run would be applying six different polyelectrolytes at the same dosage to each of the various filter columns (each column operated at the same filtration rate). Based on effluent quality data, the efficiency of one polyelectrolyte versus another could be determined, based on suspended solids reductions.

When dealing with additions of alum, lime, and ferric chloride, effluent samples were also analyzed for total and dissolved phosphates in addition to suspended solids, since one of the functions of adding these coagulants was to effectuate phosphate reductions in the process. Optimum combinations of chemicals determined from the coagulant test apparatus were then utilized for full scale pilot runs in the 6-inch column. A total of 53 polyelectrolytes were evaluated for enhancing suspended solids removals, including 9 which were of the potable water grade, that is, acceptable for potable water usage. A list of polyelectrolytes evaluated under this test work is contained in Table 3.

## In-line Suspended Solids Monitor

An in-situ meter recorder device for rapidly measuring total suspended solids content in the main flow stream, as furnished by Biospherics, Inc., was utilized in the combined sewer overflow filtration pilot plant works. Figure 7 shows the installation of the Biospherics Model 53 suspended solids monitor.

According to the manufacturer, this instrument operates (13) on the principles of measurement by both light transmittance and light scattering simultaneously. The operation is step-wise on a 15 second cycle, in which the photocell windows are wiped clean during each cycle. When the glass tube is filled with clear water, the transmittance cell receives the maximum amount of light and the scatter cell is in complete darkness. When suspended solids are added to the liquid, the transmittance photocell will receive less light due to shadows on its sensing surface and the scatter photocell will receive light due to light reflection. The response of each cell is non-linear and, therefore, not

Table 3

## LIST OF POLYELECTROLYTES

| Chemical Industries | Type of Polyelectrolytes | | |
|---|---|---|---|
| | Cationic | Nonionic | Anionic |
| Atlas Chemical Industries, Inc.<br>Wilmington, Delaware 19899 (Atlasep) | 105C | IN | 1A1,2A2,3A3,4A4,5A5 |
| American Cyanamid Company<br>Wayne, New Jersey 07470 (Magnifloc) | 521C*,560C<br>570C*,571C* | 900N,905N<br>985N*, 990N* | 835A,836A,860A*<br>865A |
| Calgon Corporation(Coagulant Aid)<br>Pittsburgh, Pennsylvania 15230 | 227, 228 | 18(*) (**) | 235, 240<br>25** |
| The Dow Chemical Company<br>Midland, Michigan 48640(Purifloc) | C-31*, C-41 | - | A-23* |
| Gamlen Chemical Company (Gamafla)<br>East Paterson, New Jersey 07407 | NC 772 | - | NA 710 |
| Hercules Incorporated (Hercofloc)<br>Hopewell, Virginia 23860 | 810, 814.2<br>828.1 | - | 816, 822, 836 |
| Nalco Chemical Company (Nalcolyte)<br>Chicago, Illinois 60601 | - | 671 | 672, 673, 675H |

Table 3

(Continued)

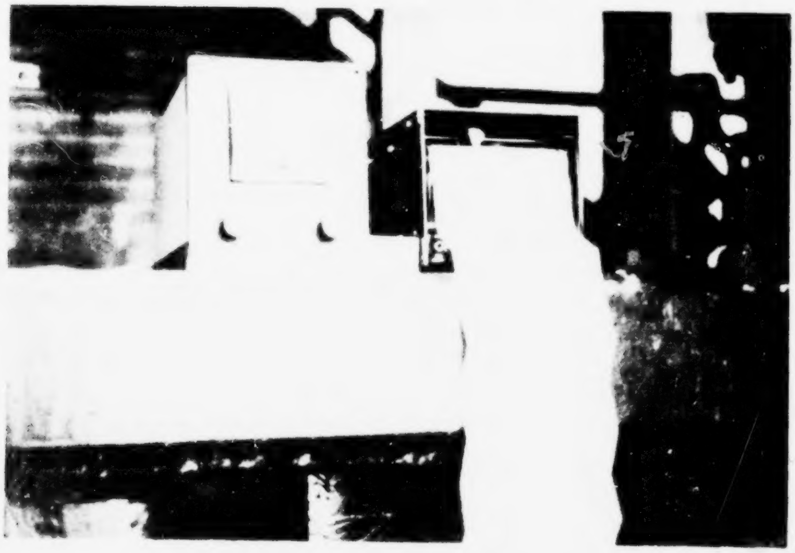
LIST OF POLYELECTROLYTES

| Chemical Industries | Type of Polyelectrolytes | | |
|---|---|---|---|
| | Cationic | Nonionic | Anionic |
| Narvon Mining and Chemical Company (Zeta Floc)<br>Lancaster, Pennsylvania 17604 | C,** CX** | WN** | WA** |
| Reichhold Chemicals, Inc.<br>Tuscaloosa, Alabama 35401 (Aqua-Rid) | 49-700, 49-701<br>49-710, 49-711 | 49-704 | - |
| Stein-Hall Chemical (Polyhall)<br>New York, New York 10016 | MRL 91 | M402 | 295A |
| Swift and Company<br>Oak Brook, Illinois 60521 | - | - | X-400 |

* Approved by EPA For Water Treatment (April 1971)

** With Bentonite Clay

SUSPENDED SOLIDS SENSOR



CONTROL UNIT AND RECORDER

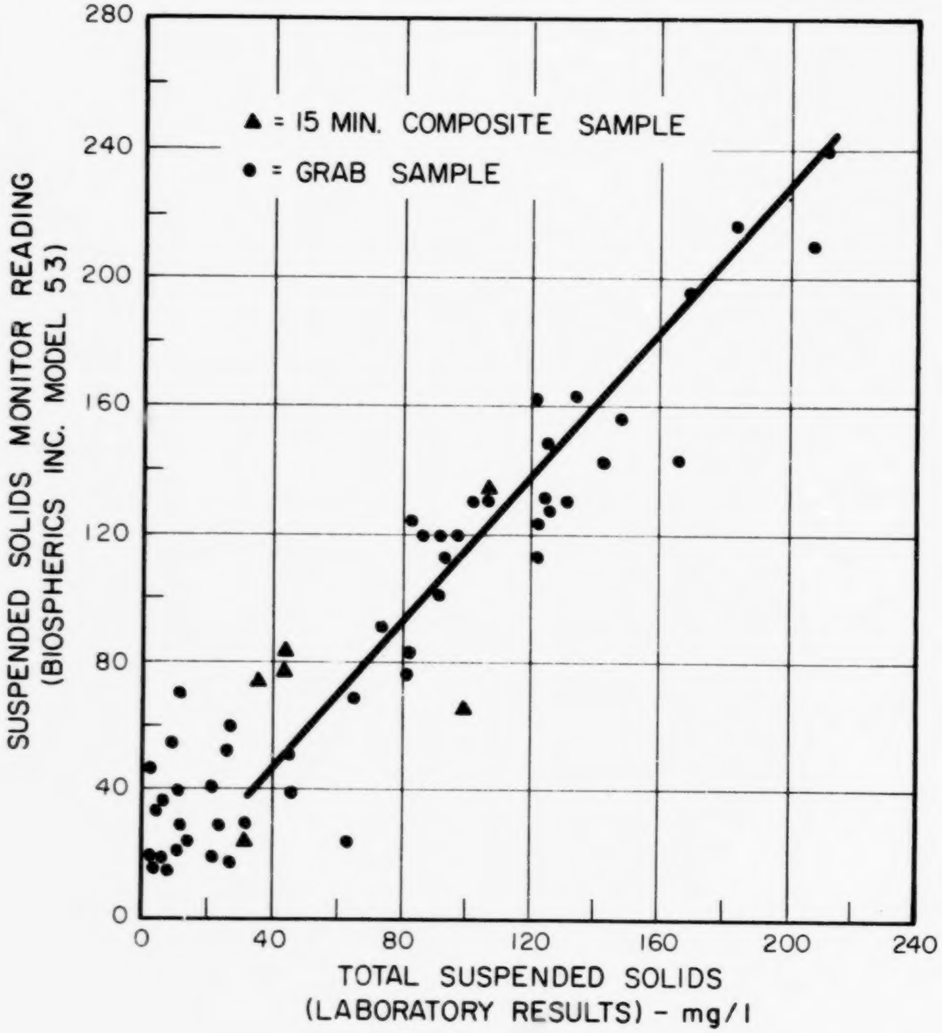
SUSPENDED SOLIDS MONITOR INSTALLATION

FIGURE 7

proportional to suspended solids concentration. However, the result obtained by dividing the response of the scatter photocell by that of the transmittance photocell is linear. This division is performed electronically and the linearity is achieved by carefully positioning the photocells in addition to the electronic division of their signals. Liquid color or light bulb intensity are claimed not to cause errors.

A relationship between the suspended solids monitor readings and laboratory analyzed suspended solids results is presented in Figure 8. It was found that the readings from the monitor gave a reasonable correlation in measuring the suspended solids for concentration range between 30 and 240 mg/l. Based on a limited verification procedure, a great scattering of readings occurred in the lower range (0 to 30 mg/l) of suspended solids concentrations which may have been caused by deviations in the laboratory bench test; possible errors in bench test procedure such as sample preparations; probability of capturing the same slug analyzed by the suspended solids monitor for direct comparison with laboratory analysis and the variation of light absorbing or reflecting characteristics of the suspended solids in the lower concentration range. However, an instrument of this kind showed a promising potential application for continuous monitoring of suspended solids level in the filter influent or effluent.

In order to establish an accurate correlation between the suspended solids value and the monitor reading, a longer term investigation procedure should be more carefully set up. Consistent and reproducible results may thus be developed. Then, the instrument could enhance the filtration plant operation by continuously recording the total suspended solids content of wastewater for the control of coagulant and flocculant feed rate combinations or flocculant feed alone and by continuous effluent monitoring for optimizing filter performance and filtrate quality by furnishing automatic positive control.



SUSPENDED SOLIDS MONITOR READING Vs LABORATORY RESULTS

FIGURE 8

## SECTION VI

## CHARACTERIZATION OF COMBINED SEWER OVERFLOWS

Combined sewer overflow characterization data (sampling point #1) was collected for thirteen storms during 1970 and for two storms during 1971. The key parameters for each storm are plotted in Figures A1 thru A15 in the Appendix. Hourly rainfall data (14) is also indicated on these plots. The rain gage is located at Cleveland's Hopkins Airport, at the western extremity of the Southerly Sewerage District, approximately ten miles west of the Southerly Wastewater Treatment Plant. These plots show the effect of time, in a storm sequence, on the magnitude of various wastewater pollutants.

Table 4 contains average data, including maximum and minimum values, for combined sewer overflow sampling in 1970. Mean suspended solids levels were 234 mg/l, with a range from 28 to 1560-702 mg/l. Biochemical oxygen demand levels average 92 mg/l, with values ranging from 16 to 580 mg/l. Chemical oxygen demand levels averaged 308 mg/l, with values ranging from 57 to 711 mg/l.

As is shown on the combined sewer overflow curves in Appendix A, concentration peaks, generally referred to as the "first flush" effect, were evidenced on storms Nos. 1, 2, 10, 11 and 12, or during five out of the thirteen combined sewage storm overflows sampled. The most pronounced concentration peak occurred during storm No. 1, when in excess of one inch of rainfall fell within one hour.

The majority of the 1970 combined sewer overflow sampling was accomplished during the months of August, September and October. In order to profile combined sewer overflow characteristics in the earlier part of the rainy season, two storms were sampled during 1971, one in early May and one in early June. Average results of these spring storms are presented in Table 5 and individual storm plots presented in Figures A-14 and A-15 in the Appendix. The data contained in Table 5 (spring storm overflows) indicates that the spring storms produce an overflow of a more highly pollutional nature, as BOD, COD, total suspended solids and settleable solids values were substantially higher than those experienced during the remainder of the summer and fall periods. As indicated in Table 5, for the spring storms, mean suspended solids levels were 462 mg/l, mean BOD was 171 mg/l and mean COD was 462 mg/l. Both of the spring storms sampled had pronounced "first flush" concentration peaks, as evidenced from Figures A-14 and A-15 in the appendices.

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Table 4

CHARACTERISTICS OF COMBINED SEWER OVERFLOWS
(late July - early November, 1970)

| Analysis | No. of Observations | Mean | Standard Deviation | Minimum | Maximum |
|---|---|---|---|---|---|
| pH | 195 | 7.0 | 0.31 | 6.4 | 8.6 |
| Temperature (°F) | 137 | 69 |  | 60 | 76 |
| Turbidity (J.T.U.) | 195 | 231 | 125 | 55 | 640 |
| Dissolved Oxygen (mg/l) | 78 | 3.40 | 2.28 | 0.98 | 9.3 |
| BOD (mg/l) | 197 | 92 | 49 | 16 | 580 |
| COD (mg/l) | 198 | 308 | 143 | 57 | 711 |
| TOC (mg/l) | 41 | 126 | 65 | 30 | 280 |
| Total Solids (mg/l) | 177 | 590 | 150 | 264 | 1238 |
| Suspended Solids (mg/l) | 193 | 234 | 135 | 28 | 1560 |
| Settleable Solids (ml./l) | 195 | 5.26 | 3.02 | 0.2 | 19 |
| Fecal Coliforms (# x $10^6$/100 ml.) | 197 | 4.55* | 5.72 | 0.09 | 49 |

* Median

## Table 5

## CHARACTERISTICS OF COMBINED SEWER OVERFLOWS
(May - early June, 1971)

| Analysis | No. of Observations | Mean | Standard Deviation | Minimum | Maximum |
|---|---|---|---|---|---|
| pH | 16 | 6.76 | 0.273 | 6.50 | 7.10 |
| Temperature ($^{o}F$) | 25 | 58 | 5.42 | 50 | 64 |
| Turbidity (J.T.U.) | 25 | 373 | 196 | 110 | 850 |
| Dissolved Oxygen (mg/l) | - | - | - | - | - |
| BOD (mg/l) | 24 | 171 | 42.4 | 85 | 245 |
| COD (mg/l) | 25 | 462 | 145.2 | 196 | 759 |
| TOC (mg/l) | - | - | - | - | - |
| Total Solids (mg/l) | 25 | 814 | 197 | 532 | 1275 |
| Suspended Solids (mg/l) | 25 | 411 | 178 | 177 | 976 |
| Settleable Solids (ml/l) | 25 | 6.98 | 4.68 | 1.5 | 14 |
| Fecal Coliforms x ($10^6$/100 ml) | 16 | 0.53* | .462 | .06 | 2.00 |
| Total Coliforms x ($10^6$/100 ml) | 25 | 27.36* | 13.15 | 7.0 | 62.0 |
| Fecal Strep x ($10^6$/100 ml) | 13 | 0.66* | 0.224 | 0.11 | 1.10 |

* Median

The Southerly Wastewater Treatment Plant serves a very large drainage area and this is probably a factor in minimizing "first flush" effects due to storms occurring in one portion of the drainage area. Also, the travel time due to the long sewer runs in this drainage area has limiting effect. Another probable factor is that most of the 1970 data was collected during late summer and fall periods, when lower intensity storms are more likely to occur. Finally, it is also possible that the sampling procedure missed some concentration peaks.

Correlating rainfall data and time of combined sewer overflow at the Southerly Wastewater Treatment Plant is difficult due to the size of the Southerly Sewerage District. Since the rain gage is located over ten miles away from the Southerly Sewage Treatment Plant, it is possible that a heavy downpour adjacent to the plant would have a pronounced effect on combined sewer overflow, without showing a corresponding effect on rainfall records, or visa-versa. For example, the concentration peak in storm No. 1 occurred approximately two hours after significant rainfall (at rain gage) while the peak in storm No. 12 occurs almost simultaneously with significant rainfall (at rain gage).

For comparative purposes, dry weather flow occurring at the Southerly Wastewater Treatment Plant was profiled for a thirty six hour period (October 10 and 11, 1970). Sampling was performed at one hour intervals. Hydrotechnic Corporation and the EPA Project Officer decided that a "round the clock" profiling of normal dry weather flow would be beneficial, especially when used for comparative purposes with storm water overflows. As shown in Table 6, mean dry weather suspended solids were 192 mg/l, with values ranging from 64 to 249 mg/l; mean BOD was 130 mg/l, with values ranging from 60 to 185 mg/l; and mean COD was 383 mg/l, with values ranging from 164 to 543 mg/l. As previously mentioned, the BOD/COD ratio of the wastewater at the Southerly Wastewater Treatment Plant (approximately 0.3) is rather low for a municipal sewage, and is due to the heavy concentration and amounts of industrial wastewater discharges into the system.

Comparing average combined sewer overflow levels (Table 4) and dry weather flow contaminant levels (Table 6) for the 1970 sampling period, suspended solids are approximately 25 percent higher than normal dry weather flow levels; combined sewer overflow BOD levels are approximately 70 percent of those experienced during the dry weather flow; and COD levels are comparable for both wastewater discharges - 383 mg/l for dry weather flow versus 308 mg/l for combined sewer overflow conditions. The median fecal coliform level for the dry weather flow at the Southerly Wastewater Treatment Plant was

## Table 6

### CHARACTERISTICS OF DRY WEATHER SEWAGE FLOW
( SOUTHERLY WASTEWATER TREATMENT PLANT)
( 9 AM - 10/28/70 to 3 PM - 10/29/70)

| Analysis | No. of Observations | Mean | Standard Deviation | Minimum | Maximum |
|---|---|---|---|---|---|
| pH | 18 | 7.6 | 0.155 | 7.3 | 8 |
| Temperature ($^{o}$F) | 18 | 63 | 1.0 | 62 | 65 |
| Turbidity (J.T.U.) | 18 | 167 | 60 | 81 | 266 |
| Dissolved Oxygen (mg/l) | 18 | 2.35 | 1.1 | 0.82 | 4.5 |
| BOD (mg/l) | 18 | 130 | 42 | 60 | 185 |
| COD (mg/l) | 18 | 383 | 112 | 164 | 543 |
| TOC (mg/l) | 18 | 116 | 37 | 65 | 174 |
| Total Solids (mg/l) | 18 | 634 | 95 | 441 | 820 |
| Suspended Solids (mg/l) | 18 | 192 | 68 | 64 | 249 |
| Settleable Solids (ml/l) | 18 | 5.3 | 2.5 | 0.5 | 9.5 |
| Fecal Coliforms (# x $10^6$/100 ml.) | 18 | 15.7* | 13.0 | 5.0 | 62.0 |

* Median

$15.7 \times 10^6$ colonies per 100 ml. The median level for the combined sewer overflows at the Southerly Plant was approximately 30 percent of this value.

For the spring storm period (May-early June), based on data collected in 1971 (see Table 4), it appears that combined sewer overflows at the Southerly Wastewater Treatment Plant are more polluted than raw sewage (in terms of total suspended solids, BOD, COD). This comparison underlines the importance of adequately handling or treating combined sewer overflows.

Figure 9 profiles dry weather sewage flow and combined sewer overflow characteristics of the Southerly Wastewater Treatment Plant for a consecutive period. Dry weather sampling (plant influent) was commenced at 9 a.m. on October 10, 1970 and continued until 4 p.m. on October 29, 1970, when combined sewer overflow sampling procedures were initiated. Sampling was terminated at 2 p.m. on October 30, 1970. This plot shows the "first flush" concentration peak occurring between 4 p.m. and 5 p.m. (1600 and 1700 hours), depending upon the particular water quality contaminant observed. The hydraulic peak or maximum combined sewer overflow discharge, occurred at 6 p.m. (1800 hours). Although the plant inflow cannot be directly related to the quantity of the combined sewer overflow occurring at the plant bypass, maximum plant flow coincides with maximum combined sewer overflow, due to the nature of the upstream overflow structure. As mentioned previously, rainfall data and combined sewer overflow characteristics cannot be directly related, due to the size of the drainage area and the distance of the rain gage from the Southerly Wastewater Treatment Plant.

The more significant characteristics of the combined sewer overflow at Southerly can be summarized as follows:

a. A total of about 52 overflows a year can be expected. Most of them have a duration of 5 to 6 hours. The majority of overflows occur from storm having a rainfall intensity of between 0.5 and .30 inches/hr (15).

b. The concentration of suspended solids generally ranged between 100 and 400 mg/l. The maximum was 1560 mg/l.

c. The concentrations of BOD generally ranged between 50 and 200 mg/l. The maximum was 580 mg/l.

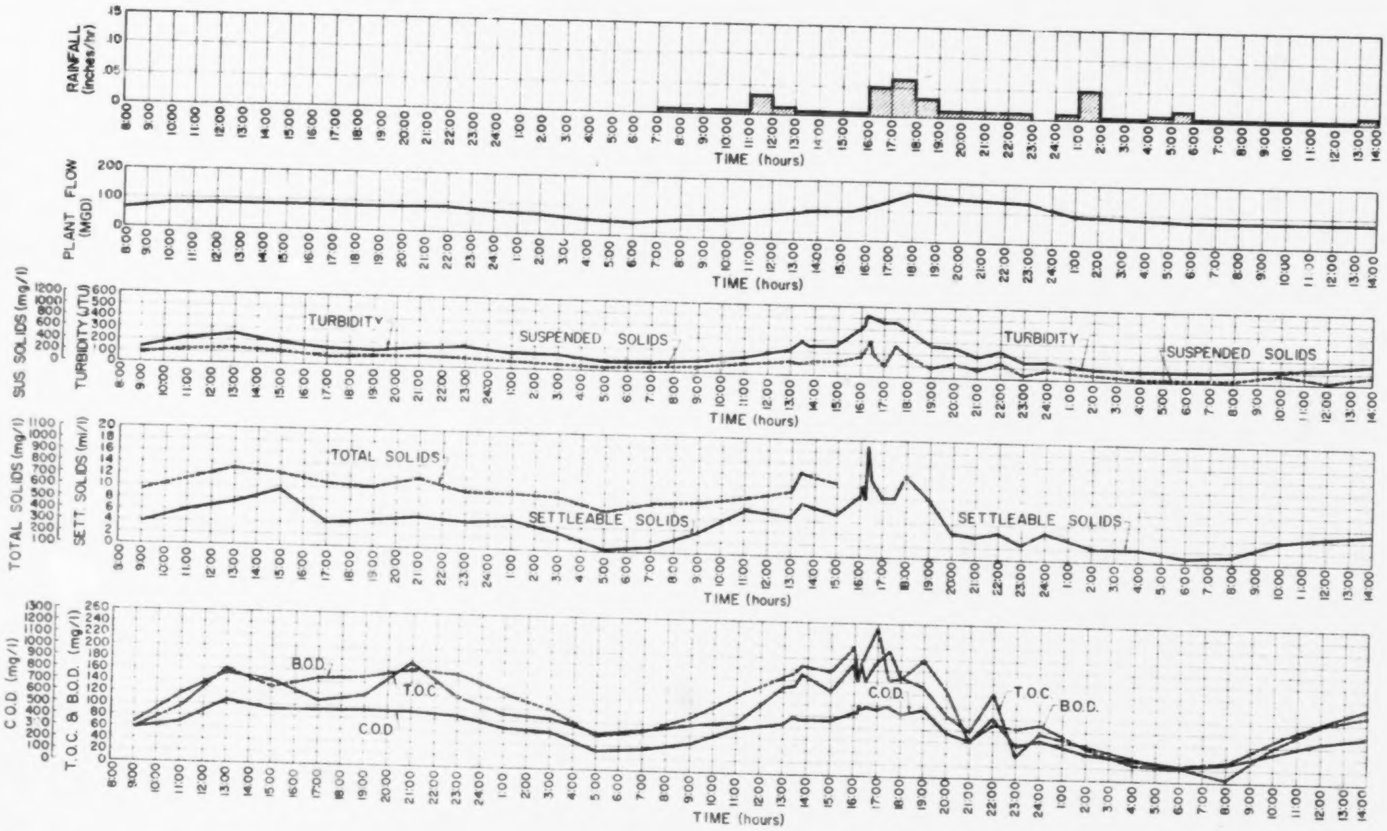

FIGURE 9

SOUTHERLY WASTEWATER TREATMENT PLANT
DRY AND WET WEATHER FLOW CHARACTERISTICS
10/28-30/70: PRECIPITATION .37 INCHES

d. The concentration of suspended solids generally reached its maximum with 1/2 hours after the beginning of the combined sewer overflow.

e. In most cases, within 3 to 4 1/2 hours the concentration of suspended solids in the combined sewer overflow dropped to less than 150 mg/l.

f. Suspended solids levels are higher than those in dry weather sewage.

g. The concentrations of BOD were generally lower than those in the dry weather sewage except for storms occurring in the spring. BOD levels were highest in the earlier phases of the combined sewer overflow.

# SECTION VII

# SCREENING RESULTS

## System Testing - Wire Mesh Screen

The function of the screen in the overall treatment system tested at the Southerly Wastewater Treatment Plant was to remove coarser material (fibrous type, etc.) that would impede the filtration operation. It was felt that the major process unit in the proposed system would be the deep bed high rate filters. The screen facility was operated at a hydraulic loading (thruput) of 100 gallons per minute per square foot for the duration of the pilot testing of screening-filtration. This level was set after a review of previous screening tests performed by others.

Testing accomplished during the first three storms utilized a No.3 mesh screen (equivalent to Tyler Screen scale 3 mesh with 6350 micron or 1/4 inch openings) ahead of the filter columns. The major function of the testing performed in the early stages was to define screen sizes and media that could produce reasonable removals and a reasonable length of filtration run.

Simply stated, the results of the first three storms demonstrated that the No. 3 mesh screen was inadequate for an effective high rate filtration operation. All test filter columns plugged within a few hours, irrespective of the filter media utilized. On one occasion, the screen itself plugged. Inspection of the screen showed that fibrous materials had matted on the screen. The matted material resembled primary paper mill sludge.

A No. 20 mesh screen equivalent to Tyler screen scale 20 mesh with 841 micron openings was installed in place of the No. 3 mesh unit. Operation of the filter test columns, preceded by the No. 20 mesh screening unit, proved feasible, as reasonable lengths of filter runs could be accomplished. No plugging problems were evidenced. Complete removal data for the No. 20 mesh screen operation is presented in Table B-2 in the Appendix. The screening data are summarized as follows:

| | | Average Influent | Average Effluent | Removal (%) |
|---|---|---|---|---|
| Suspended Solids | (1) * | 470 | 390 | 17.0 |
| (mg/l) | (2) | 219 | 173 | 21.0 |
| Settleable Solids | (1) | 10.2 | 4.8 | 52.9 |
| (ml/l) | (2) | 5.4 | 2.3 | 57.4 |
| BOD (mg/l) | (1) | 169 | 160 | 5.3 |
| | (2) | 72 | 56 | 22.2 |
| COD (mg/l) | (1) | 483 | 300 | 37.9 |
| | (2) | 175 | 146 | 16.6 |

*

(1) Run No. 4SF, Average of 5 Samples.
(2) Run No. 6SF, Average of 11 Samples.

Average removals of suspended solids, for the two storms tested, approximated 17 to 21 percent. The range of removal experienced during a screen test run was quite wide due to the extreme variation of the suspended solids concentration in the raw combined sewer overflow. For the two storms tested with the No. 20 mesh screen, the instantaneous suspended solids removals varied from 0 to 55 percent. A wide variation in removal characteristics of the screening unit was also noted for other wastewater contaminants. Previous work done by others on combined sewer overflow screening has also shown extremely variable removals in COD and BOD (16), especially in terms of BOD, which of course could also be related to the sampling techniques and the reliability of the BOD test procedure. In regards to Cleveland, the fact that a significant amount of industrial waste containing dissolved organics is generated in the Southerly Sewage District might account for the highly variable removals of COD and BOD.

Although the No. 20 mesh screen permitted a filtration run to last for a reasonable time, over 6 hours, the head losses experienced throughout the run were higher than had been noted in past high rate filtration testing of industrial waste waters. Thus, a finer screen was required, and a No. 40 mesh screen equivalent to Tyler screen scale 35 mesh with 420 micron opening was selected. The No. 40 mesh screen, although of finer construction than the No. 20 and the No. 3 mesh screen, can still be described as a sturdy type screen which could last for a substantial period of time without needing replacement. In the Hydrotechnic screen testing and in the selection of various screening sizes for this pilot program, the larger screen sizes were first utilized on the basis that the coarser screens would perform without physical failure for a longer period under the abrasive application of combined sewage storm overflow treatment. Screen failures have been experienced using finer mesh at another demonstration project (17).

Utilizing a finer screen also permitted good filtration operation. Currently, there are not enough data to compare removal characteristics of the No. 20 and the No. 40 mesh screen, although, due to the nature of the screen opening, better removals are expected by utilizing the No. 40 mesh screen. The most significant fact ascertained from the test with the No. 40 mesh screen was that the head loss through the filter columns was reduced from that experienced using a No. 20 mesh screen.

The No. 40 mesh screen was selected as the screening component of the overall treatment system. This screen appears to have sturdiness and strength of construction necessary for extended life, and also provides sufficient removals of influent suspended solids to permit reasonable filtration runs and filtration head losses. As with most screen installations, the removals of suspended solids, BOD and COD cover a variable range. The test results of seven storms (1970 test) for the No. 40 mesh screen are summarized as follows:

| | Number of Samples | Average Influent* | Average Effluent* | Removal (%) |
|---|---|---|---|---|
| Suspended Solids (mg/l) | 63 | 176 | 132 | 25.3 |
| Settleable Solids (ml/l) | 78 | 5.41 | 2.15 | 60.3 |
| BOD (mg/l) | 56 | 75 | 69 | 8.2 |
| COD (mg/l) | 56 | 268 | 209 | 22.3 |

*Average of grab samples through seven combined sewer overflows.

Supplementary Testing - Slotted Screening Element

At the end of the 1971 field test work, tests were performed to evaluate the applicability of a slotted screen element as an alternate to the mesh type screen which was used throughout all of the prior test work. The reason for evaluating the slotted type screen was due to its sturdy construction, which appears as a potential advantage, considering the abrasive nature of combined sewer overflows. The testing was accomplished by replacing the mesh screen on the rotating drum with panels of slotted screen which were furnished by the Johnson Division of UOP. Two screen meshes were tested, as shown on Table 7.

The criteria used for evaluating the slotted screen elements versus the mesh screen was filtration operation. By profiling the head loss in a deep bed, high rate filtration column, following the drum screen, determination can be made whether the screening element is removing a sufficient amount of fibrous material (which might impede filter operation) for efficient system operation. Since the testing was accomplished at the end of the test program, and due to limitations of time and money, and lack of combined sewage overflow, comparison tests were performed on raw sewage instead of combined sewage storm overflow. These test conditions are evaluating the capacity of the slotted screens to remove fibrous material. As evidenced from Table 7, head loss build up in the filter columns preceded by the slotted screen is in the order of four times as great as that when preceded by a mesh type screen. Therefore, material which contributes to filter head loss build up and filter plugging was not removed as well in the slotted screen as in the mesh type screen. Also, for the two slotted screening elements tested, the amount of flow that could be fed through the pilot drum screen system was reduced, as versus the mesh type screen. The lower percent of open area in the two slotted screen elements (see Table 7) probably accounts for the reduced flow.

In summary, the two slotted screen elements tested do not appear to provide a feasible alternate to the mesh type screen used throughout the testing program. Subsequent discussions with Johnson Screen representatives indicate that a finer screen opening (slotted variety), with a larger percent open area than the screening elements tested, might prove to be a desirable screen configuration. One of the principal assets noted was the ease in which material was removed from the slotted screen by the water sprays and, due to the heavy construction, no serious abrasion problems should be evidenced by using a slotted screen.

## Table 7

## COMPARISON OF SCREEN TYPES

| Filtration Rate (gpm/ft$^2$) | Mesh Screen | | Slotted Screen | | | |
|---|---|---|---|---|---|---|
| | Filter Following Mesh Screen (420 micron) (1) | | Filter Following Slotted Screen (400 micron) (2) | | Filter Following Slotted Screen (200 micron) (3) | |
| | Length of Run (hr.) | Total Headloss (ft.) | Length of Run (hr.) | Total Headloss (ft.) | Length of Run (hr.) | Total Headloss (ft.) |
| 16 | 6.0 | 5 | 4.5 | 27 | 6.0 | 21 |
| 24 | 6.0 | 11 | 5.0 | 35 | - | - |
| 32 | - | - | 4.5 | 35 | - | - |

(1) 43.6% open area - 100 gpm/sq ft Hydraulic Loading

(2) 21.1% open area - 45 gpm/sq ft Hydraulic Loading

(3) 11% open area - 22 gpm/sq ft Hydraulic Loading

## SECTION VIII

## DEEP BED, HIGH RATE FILTRATION RESULTS

### Evaluation of Filter Media

During the initial testing, all the filtration pilot columns, irrespective of the media utilized, plugged when preceded by the No. 3 mesh screen. Even filtration columns which contained four feet of No. 4 Anthracite (7.15 mm effective size), over four feet of No. 48 Sand (3.15 mm effective size), or contained eight feet of No. 4 Anthracite alone, a very coarse media, plugged within a few minutes to an hour.

Three storms were tested utilizing a No. 20 mesh screen prior to the filtration columns. Three anthracite sizes were evaluated in conjunction with No. 612 Sand (2.0 mm effective size) - four feet of anthracite over three feet of sand. The anthracite types included:

No. 4 Anthracite (7.15 mm effective size)
No. 3 Anthracite (4.0 mm effective size)
No. 2 Anthracite (1.78 mm effective size)

The results of these storms, summarized on Table B-3 in Appendix B, show that No. 3 Anthracite over No. 612 Sand proved to be a workable media since a reasonable length of filter run could be obtained. The filtration test columns utilizing No. 2 Anthracite in the upper layers plugged within a few hours. The test column utilizing No. 4 Anthracite, the coarsest media, plugged in less than one hour as solids were not retained in the upper layers of the filter and penetrated into, and plugged, the lower sand layer. The fine No. 2 Anthracite over the No. 612 Sand did not prove superior in removal characteristics to the No. 3 Anthracite over the No. 612 Sand. This is evidenced from Table B-3 in Appendix B. Surprisingly, the combination of No. 3 Anthracite over No. 612 Sand proved superior to the finer No. 2 Anthracite and Sand combination even though the No. 2 Anthracite is a finer media.

When preceded by No. 20 mesh screen, the No. 3 Anthracite - No. 612 Sand media combination produced a full range of suspended solids removals from 51.3 to 78.6 percent at 16 gpm/sq ft. The higher removal was experienced at an influent filter suspended solids loading of 175 mg/l, while the lower filtration efficiency was evidenced at an influent suspended solids level of 485 mg/l. Curves for all filtration runs are presented in Appendix C .

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## Selection of Screening-Filtration System Components

The No. 3 Anthracite - No. 612 Sand media was selected for more extensive testing in conjunction with the No. 40 mesh screen. The head loss experienced in the filtration column preceded by the No. 40 mesh screen was less than that utilizing a No. 20 mesh screen. As a comparison, at 16 gpm/sq ft, the head loss reading after ten hours filter operation was 10 feet with a No. 40 mesh screen versus 14 feet with a No. 20 mesh screen.

The influent suspended solids to the filters for both of these test runs was in the order of 200 mg/l. At higher filtration rates, the difference in head loss became even more pronounced and the head loss were more rapidly increased than at lower filtration rate.

In the Hydrotechnic test work, head loss through filter bed was considered as a key parameter, primarily since the application of the proposed treatment sequence in a full scale installation would be best engineered and designed around a gravity filtration system. Open vessels, which provide an avenue for gas release, appear more desirable than closed or pressure tanks when dealing with raw sewage or combined sewer overflow. The rationale is that potentially explosive gas accumulations might occur in pressure vessels, while this condition would be less prone to happen in an open gravity filter. Special precautions and design features would have to be incorporated into the engineering and operation of a filtration facility for treating combined sewer overflow which utilized closed tanks or pressure vessels, especially in applications where the dry weather sewage flow contains significant quantities of industrial wastes. For example, an explosion occurred in the one foot diameter pilot filter column (closed vessel) several hours after a filtration run had been performed in the column, and after the column was backwashed. Possibly some gas accumulations expanded and the resulting pressure caused failure of one of the plexiglass panels in the large column.

The head loss in the filter media during each filtration test run is indicated in individual data curves in Appendix C. This head loss does not include pressure losses that will occur across the filter bottom. Generally, three curves are presented for each filter run: the top curve indicating the head loss that is experienced through essentially the whole filter media, and the other curves indicating the head loss in a certain depth of the media, with the media depth measured from the top of the bed.

## Plain Filtration and Filtration with Polyelectrolyte Addition

Two basic modes of process operation were evaluated for removing suspended solids and other contaminants which were in suspended form: plain filtration and filtration with polyelectrolyte addition. Plain filtration is simply filtration without chemicals or any additives. Filtration with polyelectrolyte addition was also evaluated, since previous data on general filtrations and on industrial applications of deep bed, high rate filtration, had shown the merits of utilizing polyelectrolytes to enhance performance. The coagulant testing apparatus was utilized to select polyelectrolytes for full scale filtration runs. Visual observations and previous experience by others (18) had indicated that filtration test column runs were required to conclusively establish the true effect of the polyelectrolyte on filtration removal efficiency.

Fifty three polyelectrolytes were evaluated for enhancing filtration performance. All the work, as previously mentioned, was performed in the coagulant testing apparatus, which permitted simultaneous evaluation of six different polyelectrolytes at a time. Results of the polyelectrolyte evaluation tests are presented in Table 8. This table indicates that some polyelectrolytes are better than others in improving filter performance. Polyelectrolyte selection to be used in conjunction with deep bed high rate filtration, is critical, as is evidenced from this table. Four polyelectrolytes produced good removals (88 percent or more) and three were tested in the pilot filter columns to obtain operational data. In general, the anionic polyelectrolytes proved most effective at this particular test site.

During the 1970 test work, a number of filter runs were performed utilizing Nalcolite 671 polyelectrolyte, which was selected after a series of jar tests. Subsequently, in 1971, the coagulant test apparatus was installed and permitted a realistic method of selecting a polyelectrolyte. Therefore, the data from the 1970 test work, utilizing the Nalcolite 671 polyelectrolyte, is not considered applicable to the performance that can be achieved in the proposed system via the appropriate polyelectrolyte.

Complete test results for all the filtration tests are presented in Table B-3 through B-6 in Appendix B. For the recommended system (5 feet of No. 3 Anthracite over 3 feet of No. 612 Sand), suspended solids removals with or without polyelectrolyte addition, are presented in Figure 10. Suspended solids removals increased appreciably with the addition of an appropriate polyelectrolyte and ranged from 90.4 percent at 24 gpm/sq ft to 96.7 percent at 8 gpm/sq ft at an influent concentration of 300.7 mg/l. Suspended solids reduction without polyelectrolytes

Table 8

## RESULTS OF POLYELECTROLYTE SELECTION TESTS

| Polyelectrolytes | Type | Total Suspended Solids<br>Influent (mg/l) | Effluent (mg/l) | Removal (%) |
|---|---|---|---|---|
| Atlasep 1A1 | Anionic | 204 | 60 | 71 |
| Atlasep 2A2 | Anionic | 513 | 182 | 65 |
| Atlasep 3A3 | Anionic | 204 | 27 | 87 |
| Atlasep 4A4 | Anionic | 181 | 13 | 93 |
| Atlasep 5A5 | Anionic | 204 | 39 | 81 |
| Calgon 235 | Anionic | 250 | 170 | 30 |
| Calgon 240 | Anionic | 248 | 63 | 75 |
| Gamafloc NA710 | Anionic | 248 | 36 | 86 |
| Hercofloc 816 | Anionic | 164 | 24 | 85 |
| Hercofloc 822 | Anionic | 164 | 32 | 81 |
| Hercofloc 836 | Anionic | 164 | 20 | 88 |
| Magnifloc 835A | Anionic | 236 | 98 | 58 |
| Magnifloc 836A | Anionic | 236 | 95 | 60 |
| Magnifloc 860A* | Anionic | 236 | 206 | 13 |
| Magnifloc 865A | Anionic | 181 | 87 | 52 |
| Nalcolyte 672 | Anionic | 248 | 72 | 71 |
| Nalcolyte 673 | Anionic | 231 | 78 | 66 |
| Nalcolyte 675H | Anionic | 231 | 4 | 97 |
| Polyhall 295A | Anionic | 513 | 250 | 51 |
| Purifloc A23* | Anionic | 164 | 20 | 88 |
| Swift X400 | Anionic | 513 | 199 | 61 |
| Aqua-Rid 49700 | Cationic | 478 | 252 | 47 |
| Aqua-Rid 49701 | Cationic | 478 | 202 | 58 |
| Aqua-Rid 49710 | Cationic | 478 | 184 | 65 |
| Aqua-Rid 49711 | Cationic | 478 | 244 | 49 |
| Atlasep 105C | Cationic | 181 | 66 | 64 |
| Calgon 227 | Cationic | 250 | 152 | 39 |
| Calgon 228 | Cationic | 250 | 188 | 25 |
| Gamafloc NC722 | Cationic | 248 | 158 | 36 |
| Hercofloc 810 | Cationic | 236 | 41 | 83 |
| Hercofloc 814.2 | Cationic | 236 | 194 | 18 |
| Hercofloc 828.1 | Cationic | 236 | 182 | 23 |

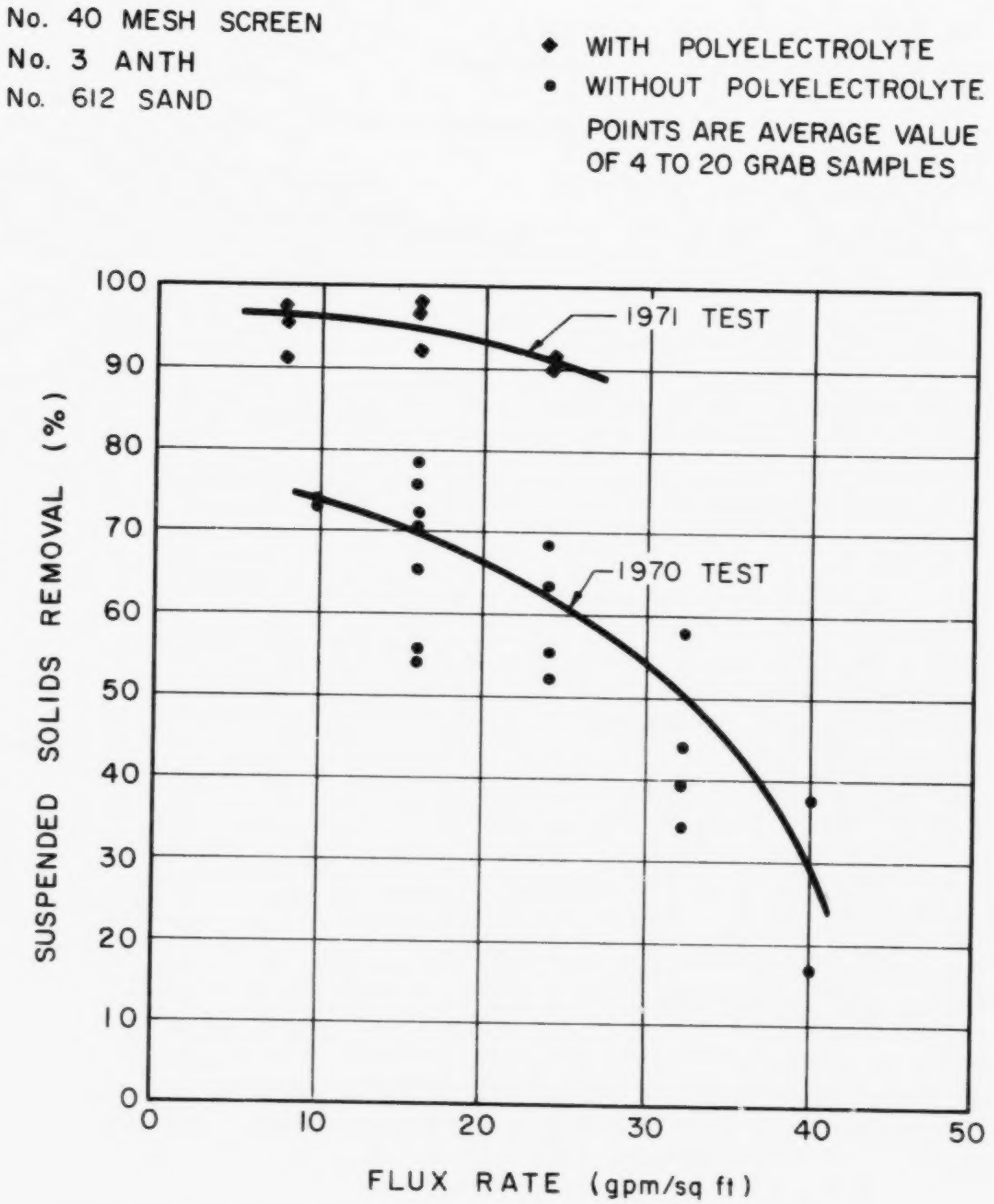
## Table 8
(Continued)

## RESULTS OF POLYELECTROLYTE SELECTION TESTS

| Polyelectrolytes | Type | Total Suspended Solids Influent (mg/l) | Effluent (mg/l) | Removal (%) |
|---|---|---|---|---|
| Magnifloc 521C* | Cationic | 250 | 200 | 20 |
| Magnifloc 560C | Cationic | 181 | 10 | 94 |
| Magnifloc 570C* | Cationic | 250 | 140 | 44 |
| Magnifloc 571C* | Cationic | 250 | 166 | 34 |
| Polyhall MRL 91 | Cationic | 513 | 264 | 49 |
| Purifloc C-31* | Cationic | 164 | 27 | 84 |
| Purifloc C-41 | Cationic | 164 | 93 | 43 |
| Aqua-Rid 49704 | Nonionic | 478 | 164 | 66 |
| Atlasep 1N | Nonionic | 181 | 65 | 64 |
| Magnifloc 900N | Nonionic | 204 | 118 | 42 |
| Magnifloc 905N | Nonionic | 181 | 85 | 53 |
| Magnifloc 985N* | Nonionic | 204 | 106 | 48 |
| Magnifloc 990N* | Nonionic | 204 | 108 | 47 |
| Nalcolyte 671 | Nonionic | 189 | 64 | 66 |
| Polyhall M402 | Nonionic | 513 | 373 | 27 |
| Calgon No. 18* | (1) | 248 | 114 | 54 |
| Calgon No. 25 | (2) | 248 | 170 | 31 |
| Zetafloc WN | (3) | 513 | 330 | 35 |
| Zetafloc WA | (2) | 189 | 89 | 53 |
| Zetafloc C | (4) | 189 | 103 | 46 |
| Zetafloc CX | (4) | 185 | 97 | 49 |

* Approved by EPA for Water Treatment (April 1971)
(1) Nonionic, High M.W. Polyelectrolyte Polymer & Bentonite Clay Mixture
(2) Anionic and Bentonite clay or Aluminum Silicate Mixture
(3) Nonionic and Aluminum Silicate Mixture
(4) Cationic and Aluminum Silicate Mixture

Note: Flux Rate (20-24 gpm/sq ft ), three hour composite samples.



MEAN SUSPENDED SOLIDS REMOVALS BY FILTRATION

FIGURE 10

ranged from 37.5 at 40 gpm/sq ft to 72.8 percent at 10 gpm/sq ft at influent concentration of 152 and 114 mg/l, respectively. Suspended solids removal is the chief criterion for process efficiency. A summary of filtration test results for two typical combined sewer overflows are shown on Table 9.

Table 9

SUSPENDED SOLIDS REMOVALS BY FILTRATION

| Filtration Rate (gpm/sq ft) | Number of Samples | Average Influent (mg/l) | Average Effluent (mg/l) | Removal % |
|---|---|---|---|---|
| Plain (1970) | | | | |
| 10 | 13 | 114 | 31 | 72.8 |
| 16 | 17 | 205 | 48 | 76.6 |
| 24 | 13 | 114 | 74 | 35.1 |
| 32 | 4 | 132 | 80 | 39.4 |
| 40 | 4 | 152 | 95 | 37.5 |
| With Polyelectrolyte (1.0 mg/l) (1971) | | | | |
| 8 | 6 | 300.7 | 10.0 | 96.7 |
| 16 | 6 | 300.7 | 9.0 | 97.0 |
| 24 | 6 | 300.7 | 28.0 | 90.4 |

Similar to suspended solids, settleable solids removals increase appreciably with the introduction of appropriate polyelectrolyte, as shown in Table 10. For filtration rates between 8 and 24 gpm/sq ft with polyelectrolyte addition, settleable solids removals were 92.8 to 90.7 percent, respectively. Effluent settleable solids values are in the order of 0.1 ml/l.

Table 10

SETTLEABLE SOLIDS REMOVALS BY FILTRATION

| Filtration Rate (gpm/sq ft ) | Number of Samples | Average Influent (ml/l) | Average Effluent (ml/l) | Removal (%) |
|---|---|---|---|---|
| Plain<br>(1970, 1971) | | | | |
| 10 | 12 | 2.0 | .07 | 96.5 |
| 16 | 6 | 2.3 | .3 | 87.0 |
| 24 | 4 | 2.4 | .3 | 87.5 |
| 32 | 11 | .72 | .13 | 81.9 |
| 40 | 7 | 1.9 | .4 | 78.9 |
| With Polyelectrolyte (1.0 mg/l)<br>(1971) | | | | |
| 8 | 6 | 1.4 | 0.1 | 92.8 |
| 16 | 6 | 1.4 | 0.1 | 92.8 |
| 24 | 6 | 1.4 | .13 | 90.7 |

Table 11 shows the effect of deep bed, high rate filtration on the removal of organic pollutants, measured as biochemical oxygen demand (BOD), and chemical oxygen demand (COD). BOD removals cover a variable range, both with and without polyelectrolyte addition to the filtration process. Without chemicals, the reductions varied from 7.5 to 36.4 percent at filtration rates of 32 and 10 gpm/sq ft and average influent concentrations of 93 and 77 mg/l, respectively. With the addition of polyelectrolyte, reductions varied from 53.3 to 59.7 percent at filtration rate of 24 and 8 gpm/sq ft and an influent concentration of 67 mg/l. As shown in Table 11, two factors seem apparent: first, there doesn't seem to be any significant correlation between filtration rate and BOD removal, and secondly, process performance with polyelectrolyte addition is substantially better than without polyelectrolyte addition. The nature of the Cleveland combined sewer overflow, one which contains a heavy industrial contribution, may account for the variable BOD removals. Also, the reliability and reproducibility of BOD test results when dealing with a sewage with industrial waste components may be a factor.

For removals of COD, the data without polyelectrolyte addition generally follows an expected trend, that is better removals at low filtration rates. These data for process efficiency with polyelectrolyte addition do not seem to show a discernible trend for removals in filtration

Table 11

## BOD AND COD REMOVALS BY FILTRATION

| | | BOD | | | COD | | |
|---|---|---|---|---|---|---|---|
| Filtration Rate (gpm/sq ft ) | Number of Samples | Average Influent (mg/l) | Average Effluent (mg/l) | Removal (%) | Average Influent (mg/l) | Average Effluent (mg/l) | Removal (%) |
| Plain (1970) | | | | | | | |
| 10 | 13 | 77 | 49 | 36.4 | 117 | 44 | 62.4 |
| 16 | 20 | 53 | 45 | 15.1 | 118 | 82 | 30.5 |
| 24 | 13 | 77 | 67 | 13.0 | 117 | 83 | 29.1 |
| 32 | 6 | 93 | 86 | 7.5 | 244 | 187 | 23.4 |
| 40 | 4 | 78 | 68 | 12.8 | 139 | 83 | 40.3 |
| With polyelectrolyte (1.0 mg/l) (1971) | | | | | | | |
| 8 | 6 | 67.0 | 27.0 | 59.7 | 161.2 | 44.5 | 72.4 |
| 16 | 6 | 67.0 | 27.5 | 59.0 | 161.2 | 73.5 | 54.4 |
| 24 | 6 | 67.0 | 31.3 | 53.3 | 161.2 | 70.5 | 55.6 |

ranges of 8 to 24 gpm/sq ft. This may be due to the fact that suspended solids removals were substantially similar at 24 gpm/sq ft and at 8 gpm/sq ft for process operation with addition of appropriate chemical. Removals with polyelectrolyte addition ranged from 55.6 to 72.4 percent at filtration rates of 24 and 8 gpm/sq ft , respectively.

More limited data on removals of total organic carbon by filtration (1970 test data) indicate removals ranging from 42.5 percent at 32 gpm/sq.ft. with influent and effluent concentrations of 135.7 and 78.0 mg/l, respectively, to 62.7 percent at 10 gpm/sq ft reducing the influent concentration from 67.0 to 25.0 mg/l in the effluent for process operation with polyelectrolyte addition. Percentagewise, total organic carbon removals are higher than the respective COD removals.

Table 12 shows the process performance in regard to phosphorus removal, an important consideration where the effluent is discharged to a lake. This table illustrates that total phosphorus removal, with polyelectrolyte addition, does not seem to be substantially influenced by filtration rates in the range of 8 to 24 gpm/sq ft . Each of the two polyelectrolytes shown on the table were considered as an optimum polyelectrolyte. The results for the phosphorus reductions utilizing the two polyelectrolytes are in the order of 30-50 percent.

Table 12

TOTAL PHOSPHORUS REMOVALS BY FILTRATION

| Filtration Rate (gpm/sq ft ) | Number of Samples | Average Influent (mg/l) | Average Effluent (mg/l) | Removal (%) |
|---|---|---|---|---|
| With Polyelectrolyte Purifloc A23 (1.0 mg/l) | | | | |
| (1971) | | | | |
| 8 | 6 | 0.71 | 0.43 | 39.4 |
| 16 | 6 | 0.71 | 0.39 | 45.1 |
| 24 | 6 | 0.71 | 0.40 | 43.7 |
| With Polyelectrolyte Magnifloc 560C (1.0 mg/l) | | | | |
| (1971) | | | | |
| 8 | 6 | 0.76 | 0.40 | 47.2 |
| 16 | 6 | 0.76 | 0.36 | 52.6 |
| 24 | 6 | 0.76 | 0.55 | 26.3 |

Results on removal of nitrogen, a factor considered critical to lake eutrophication, in some cases indicates removals ranging from 10.9 to 42.5 percent (filtration without polyelectrolyte - 1970 data) with an average influent concentration of 8.7 to 23.2 mg/l. Table B-6 in Appendix B presents the test results.

Table 13 gives a further breakdown as to the nature of solids removals by high rate filtration tested in 1970. For filtration rates of 10, 16, and 24, gpm/sq ft , removals are shown for total nonvolatile solids, total volatile solids, total suspended solids, total nonvolatile suspended solids, and total volatile suspended solids. The major deduction from this table is that removals of nonvolatile suspended solids are greater than removals of volatile suspended solids. In other words, the inert or inorganic solids are more amenable to removal by high rate filtration. As a possible extension of these results, one might suspect that, as the nature of the solids in combined sewer overflow becomes more of a nonvolatile variety than a volatile suspended solids variety, overall system removal of suspended solids would increase. Another possible extension of this data trend suggests that the filtration process would be more effective with urban runoff than for combined sewer overflows, as the nature of the suspended solids in urban runoff normally tends to be more of a nonvolatile suspended solids or inert variety, as contrasted to combined sewer overflows (19).

Table 14 summarizes the removal data of greases by high rate filtration. As shown by this tabulation, the test data was subject to significant variability, with removals ranging from 31.6 to 45.5 at filtration rates of 32 and 16 gpm/sq ft with composite influent concentration of 28.4 and 25.5 mg/l, respectively. The analysis and interpretation of the greases in sewage has always been a difficult problem, especially where significant amounts and varieties of industrial wastes are present, as in Cleveland. During the 1970 testing program, several results showed extremely high oil and grease concentrations. The cause of these high values could not be determined but a note on the result sheet from the laboratory running the analyses indicated that the residue experienced at the end of the laboratory test did not resemble normal ether extractable residue.

For plain filtration tests, the length of run was generally in the range of 6-10 hours for flow rates of 24 gpm/sq ft or less. Filtration head losses at 16 gpm/sq ft would generally be less than 15 feet and ranged up to 30 feet and greater for the higher filtration rates. No deterioration of effluent quality with time or length of filter run was normally evidenced for the plain filtration mode of operation. At the end of a filter run, visual observations revealed that solids had penetrated throughout the depth of the filter media.

Table 13

## SOLIDS REMOVALS BY FILTRATION

| Filtration Rate (gpm/sq ft ) | Number of Samples | Average Influent (mg/l) | Average Effluent (mg/l) | Removal (%) |
|---|---|---|---|---|
| Total Nonvolatile Solids (1970) | | | | |
| 10 | 5 | 202 | 162 | 19.9 |
| 16 | 3 | 139 | 112 | 19.4 |
| 24 | 5 | 202 | 167 | 17.3 |
| Total Volatile Solids (1970) | | | | |
| 10 | 5 | 108 | 136 | 24.4 |
| 16 | 3 | 118 | 95 | 19.5 |
| 24 | 5 | 180 | 175 | 2.8 |
| Total Suspended Solids (1970) | | | | |
| 10 | 5 | 116 | 30 | 74.0 |
| 16 | 5 | 116 | 37 | 68.0 |
| 24 | 5 | 116 | 63 | 45.7 |
| Total Nonvolatile Suspended Solids (1970) | | | | |
| 10 | 5 | 54 | 9 | 83.0 |
| 16 | 5 | 54 | 12 | 78.0 |
| 24 | 5 | 54 | 26 | 52.0 |
| Total Volatile Suspended Solids (1970) | | | | |
| 10 | 5 | 62 | 21 | 66.0 |
| 16 | 5 | 62 | 23 | 63.0 |
| 24 | 5 | 62 | 39 | 37.0 |

Note: Data from runs using 1.5 mg/l of Nalcolyte 671
(not optimum polyelectrolyte control)

Table 14

## GREASE REMOVALS BY FILTRATION

| Filtration Rate (gpm/sq ft ) | Average* Influent (mg/l) | Average* Effluent (mg/l) | Removal (%) |
|---|---|---|---|
| Plain (1970) | | | |
| 16 | 25.5 | 13.9 | 45.5 |
| 24 | 28.4 | 16.4 | 45.1 |
| 32 | 28.4 | 19.4 | 31.6 |
| With Polyelectrolyte** (1970) | | | |
| 10 | 10.9 | 5.5 | 49.5 |
| 16 | 23.0 | 6.5 | 31.8 |
| 24 | 28.4 | 16.4 | 45.1 |
| 32 | 48.4 | 27.5 | 43.2 |

* Composite sample over 6 hours period.
** With Nalcolyte 671 1.5 mg/l (not optimum polyelectrolyte)

For filtration with addition of appropriate polyelectrolyte, test runs ranged between 3 and 6 hours before a discernible increase in effluent solids was evidenced. The length of run was terminated at the point at which substantial deterioration of effluent quality was evidenced. The length of run and head loss data for this mode of test operation are indicated in Table B-3 in Appendix B. Head losses were generally below 15 feet at flux rates of 8 gpm/sq ft and ranged up to approximately 40 feet at flux rates of 24 gpm/sq ft For test runs using Atlasep 4A4, an accumulation of a few inches of material was noted on the surface of the filter media, although visual observation indicated that solids had also penetrated throughout the depth of the media. No problems were experienced in backwashing this accumulation from the top of the media. In a full scale filtration facility, utilizing the deep bed, high rate filtration process with the addition of appropriate polyelectrolyte, the process would be controlled by both head loss and effluent quality, as is discussed in Section X.

Removal of coliforms, both fecal and total, via the deep bed, high rate filtration process does not seem to be influenced by filtration rate, or polyelectrolyte addition. Removal data covers an extremely broad range with fecal coliform removals varying from 9.8 to 82.2 percent

(Table B-4 in Appendix B). Total coliform removals vary between 0 and 93.4 percent. An interesting observation is that total coliform removals are generally higher than fecal coliform removals. However, the removal of coliforms in the filter bed is insignificant for the purpose of disinfection.

## Filtration with Coagulant Addition - Phosphate Reducing Coagulants

A major portion of the 1971 test work was centered on evaluating the effectiveness of adding coagulants that would convert soluble phosphorus to the insoluble form, with the intention of subsequently removing it on the deep bed, high rate filter. To evaluate this mode of operation, a series of preliminary tests were performed in the coagulant testing apparatus to evaluate chemicals and polyelectrolytes to be used in this mode of operation. Initial testing evaluated alum, ferric chloride, and lime. Initial test coagulant dosages were selected by utilizing the following ratios by weight: 2 Alum/P, 1 $FeCl_3/P$ and 4.5 $Ca\ (OH)_2/P$. The 1970 data had indicated an average phosphorus (P) value of 3.3 mg/l which was utilized to determine initial test dosages.

The results of the coagulant selection tests are indicated in Table 15, including one run of lime, one run of ferric chloride, and the rest with alum. Alum was selected for this application after comparison with lime and ferric chloride. In trial runs, it was found that lime created a turbid effluent with plugging problems and that ferric chloride occasionally produced an orange yellow colored effluent.

An extended series of tests was performed utilizing various dosages of alum and various polyelectrolytes, as shown in Table 15. Process performance in terms of suspended solids removal and in terms of total phosphorus removal was quite variable. On some occasions, exceptionally good removals (in the order of 90 percent of suspended solids and phosphates were attained, while on other occasions, utilizing similar coagulant dosages and polyelectrolyte dosages, process performance was very poor (in the order of 30 percent removal or less).

To evaluate this mode of process operation further, a series of pilot filter column runs were performed to obtain operational data. Complete results are presented in Table B-3 (Sheet Nos. 5-7) in Appendix B.

Table 16 presents suspended solids removals from three combined sewer overflows for the process using alum and various polyelectrolytes.

# Table 15

## COAGULANT SELECTION TESTS
## (THREE INCH DIAMETER FILTER)

| Date | Coagulant | Polyelectrolyte | Flux Rate (gpm/ft$^2$) | Total Suspended Solids Influent (mg/l) | Total Suspended Solids Effluent (mg/l) | Total Suspended Solids Removal % | Total Phosphorus (P) Influent (mg/l) | Total Phosphorus (P) Effluent (mg/l) | Total Phosphorus (P) Removal % |
|---|---|---|---|---|---|---|---|---|---|
| 6/1 | Alum 50 mg/l | Magnifloc 560C (1 mg/l) | 20 | 214 | 20 | 90 | 12.1 | 3.0 | 75 |
| 6/1 | Alum 25 mg/l | Magnifloc 560C (1 mg/l) | 20 | 214 | 42 | 80 | 12.0 | 4.3 | 64 |
| 6/3 | Alum 20 mg/l | Magnifloc 560C (1 mg/l) | 16 | 192 | 24 | 87 | 7.5 | 2.0 | 73 |
| 6/3 | Alum 40 mg/l | Magnifloc 560C (1 mg/l) | 16 | 192 | 60 | 69 | 7.5 | 2.9 | 61 |
| 6/9 | Alum 50 mg/l | Magnifloc 560C (1 mg/l) | 24 | 274 | 42 | 85 | .58 | .04 | 93 |
| 6/9 | Alum 25 mg/l | Magnifloc 560C (1 mg/l) | 24 | 274 | 18 | 94 | .58 | .04 | 93 |
| 7/8 | Alum 30 mg/l | Magnifloc 560C (1 mg/l) | 20 | 244 | 170 | 30 | .96 | .76 | 21 |
| 6/3 | Alum 40 mg/l | Atlasep 4A4 (1 mg/l) | 16 | 192 | 96 | 50 | 7.5 | 5.4 | 28 |
| 6/9 | Alum 50 mg/l | Atlasep 4A4 (1 mg/l) | 24 | 274 | 6 | 98 | .58 | <.01 | 98 |
| 6/9 | Alum 25 mg/l | Atlasep 4A4 (1 mg/l) | 24 | 274 | 12 | 96 | .58 | .03 | 96 |
| 7/8 | Alum 30 mg/l | Atlasep 4A4 (1 mg/l) | 19 | 92 | 66 | 28 | 1.05 | 1.0 | 5 |
| 7/8 | Alum 30 mg/l | Atlasep 3A3 (1 mg/l) | 19 | 92 | 82 | 11 | 1.05 | .96 | 10 |
| 7/14 | Alum 30 mg/l | Atlasep 3A3 (.5 mg/l) | 24 | 84 | 18 | 79 | .23 | .08 | 65 |
| 8/11 | Alum 30 mg/l | Atlasep 3A3 (.25 mg/l) | 24 | 84 | 22 | 74 | .23 | .10 | 57 |
| 7/8 | Alum 30 mg/l | Swift X-400 (1 mg/l) | 19 | 92 | 54 | 41 | 1.05 | .55 | 48 |
| 8/11 | Alum 30 mg/l | Swift X-400 (1 mg/l) | 16 | 54 | 23 | 5 | .45 | .34 | 25 |
| 7/8 | Alum 30 mg/l | *Purifloc A-23 (1 mg/l) | 20 | 244 | 106 | 57 | .96 | .65 | 32 |
| 7/14 | Alum 30 mg/l | *Purifloc A-23 (1 mg/l) | 24 | 84 | 26 | 69 | .23 | .09 | 61 |
| 7/8 | Alum 30 mg/l | *Purifloc C-31 (1 mg/l) | 20 | 244 | 172 | 30 | .96 | .73 | 24 |
| 7/14 | Alum 30 mg/l | *Purifloc C-31 (1 mg/l) | 24 | 84 | 32 | 62 | .23 | .10 | 57 |
| 7/8 | Alum 30 mg/l | Nalcolyte 675H | 20 | 244 | 144 | 41 | .96 | .76 | 21 |
| 6/1 | $FeCl_3$ ** 25 mg/l | Magnifloc 560C (1 mg/l) | 20 | 214 | 58 | 73 | 12.0 | 3.1 | 74 |
| 6/1 | $Ca(OH)_2$ (120 mg/l) | --- | Filter Plugged within 15 minutes | Very | Turbid | Effluent | | | |

* Approved by EPA for Potable Water Treatment.

** Discernable orange color in effluent.

Table 16

SUSPENDED SOLIDS REMOVALS WITH ALUM AND POLYELECTROLYTE ADDITION

| Filtration Rate (gpm/sq ft) | Number of Samples | Average Influent (mg/l) | Average Effluent (mg/l) | Removal (%) |
|---|---|---|---|---|
| With Alum (30 mg/l) and Purifloc A-23 (1.0 mg/l) (1971) | | | | |
| 8 | 6 | 159.7 | 59.7 | 62.6 |
| 16 | 6 | 159.7 | 54.0 | 66.2 |
| 24 | 6 | 159.7 | 92.5 | 42.1 |
| With Alum (30 mg/l) and Magnifloc 560C (1.0 mg/l) (1971) | | | | |
| 8 | 6 | 301.7 | 108.0 | 64.2 |
| 16 | 6 | 324.5 | 181.0 | 44.2 |
| 24 | 6 | 192.2 | 48.0 | 75.0 |
| With Alum (30 mg/l) and Purifloc C-31 (1.0 mg/l) (1971) | | | | |
| 8 | 4 | 217.5 | 38.0 | 82.5 |
| 16 | 4 | 217.5 | 65.3 | 70.0 |
| 24 | 4 | 222.5 | 89.0 | 60.0 |

The alum dosage was 30 mg/l and the polyelectrolyte dosage was 1 mg/l. The results contained in this tabulation confirm the fact that the variable performance, in terms of suspended solids removal, occurs similar to the results obtained in the small-scale coagulant-testing apparatus. Process performance does improve with decreasing filtration rate. Filter length of run generally varied from three to six hours, with the run arbitrarily terminated when an appreciable solids breakthrough was evidenced. Head loss values range from below 5 feet at a flux rate of 8 gpm/sq ft to approximately 40 feet at a flux rate of 32 gpm/sq ft. Generally, an accumulation of 4 to 5 inches was noticed on top of the filter media, as this accumulation would gradually build up throughout the filtration run. In addition, depth penetration of solids throughout the media was also observed. In fact, after approximately two hours, the media appeared saturated with solids. No backwash problems were evidenced as the material was readily removed from the media.

Table 17 shows BOD and COD removals by high rate filtration with alum and polyelectrolyte addition for a typical combined sewer overflow. The COD and BOD reductions were approximately equal. Greater COD than BOD reductions could be anticipated on the basis of previous test work at lower filtration rates.

Table 17

BOD AND COD REMOVALS WITH ALUM AND POLYELECTROLYTE ADDITION*

| Filtration Rate (gpm/sq ft ) | Number of Samples | Average Influent (mg/l) | Average Effluent (mg/l) | Removal (%) |
|---|---|---|---|---|
| BOD (1971) | | | | |
| 8 | 4 | 65.8 | 31.5 | 52.1 |
| 16 | 4 | 65.8 | 34.5 | 47.6 |
| 24 | 4 | 65.8 | 30.0 | 54.4 |
| COD (1971) | | | | |
| 8 | 4 | 163.8 | 47.0 | 71.3 |
| 16 | 4 | 163.8 | 101.5 | 32.0 |
| 24 | 4 | 163.8 | 126.3 | 22.9 |

* With Alum 30 mg/l and Purifloc C-31 1.0 mg/l.

As shown in Table 18, total phosphorus reductions at average influent concentration of 0.9 mg/l were 73.3, 47.8 and 42.2 percent at filtration rate of 8, 16 and 24 gpm/sq ft , respectively. Similar to the performance experienced in the coagulant testing apparatus, total phosphorus reductions parallel suspended solids reductions. Comparing influent and effluent soluble phosphate values, coagulant addition (30 mg/l alum) prior to filtration converts approximately 65 to 70 percent of the soluble phosphate present in the wastewater to the insoluble form.

The actual use of alum in the molar ratio of 2 Al/P should provide complete conversion of soluble phosphate to insoluble aluminum phosphate. The lower results obtained indicate that more thorough mixing at the point of injection should have been accomplished in order to utilize the aluminum ion for fast aluminum phosphate formation rather than allowing the aluminum to be made unavailable for phosphate removal by the slower reaction to form aluminum hydroxide.

Table 18

TOTAL PHOSPHORUS REDUCTIONS WITH
ALUM AND POLYELECTROLYTE ADDITION

| Filtration Rate (gpm/sq ft ) | Number of Samples | Average Influent (mg/l) | Average Effluent (mg/l) | Removal (%) |
|---|---|---|---|---|
| With Alum (30 mg/l) and Purifloc A23 (1.0 mg/l) | | | | |
| (1971) | | | | |
| 8 | 6 | 0.90 | 0.24 | 73.3 |
| 16 | 6 | 0.90 | 0.47 | 47.8 |
| 24 | 6 | 0.90 | 0.52 | 42.2 |
| With Alum (30 mg/l) and Magnifloc 560C (1.0 mg/l) | | | | |
| (1971) | | | | |
| 8 | 6 | 0.61 | 0.16 | 73.8 |
| 16 | 6 | 0.57 | 0.37 | 35.0 |
| 24 | 6 | 0.51 | 0.19 | 62.7 |

It appears that this mode of process operation is applicable to a situation where there is a substantial amount of dissolved phosphate in the wastewater, and where phosphate removal is of greater importance than suspended solids removal.

Significance of Storage on Filtration Test Results

Section IV described the pilot plant sequence and process units utilized in the test work at the Southerly Wastewater Treatment Plant. The influent to the filters was abstracted from a storage tank equipped with an agitator to keep solids in suspension. The combined sewer overflow was pumped to a drum screen, whence it flowed to the storage tanks. For most of the test runs, the storage tank was filled with a sufficient quantity of combined sewer overflow for filtration test runs before the duration of the combined sewer overflow had elapsed. The screen was operated throughout the entire duration of the combined sewer overflow, which was determined by observing the influent of the Southerly Wastewater Treatment Plant.

In essence, since the storage tanks were generally filled within 30 minutes, the filtration portion of the testing was conducted on a sample of wastewater which can be described as characteristic of the earlier stages of combined sewer overflow. Thus, the average filter influent during a test run was generally greater in concentration than the average screen effluent, due to the fact that the filtration influent sample was collected during the earlier part of the storm, when higher suspended solids normally prevail. Table 19 compares average screen effluent and average filter influent for the test runs.

In regard to solids sedimentation in the storage tank between the screening unit and the filtration test columns, it was apparent that the mixing devices set up in the tank were sufficient to prevent deposition, since no significant accumulations of solid materials were evidenced at the bottom of the tank after a filtration test run. Therefore, the test set-up and arrangement, although not exactly identical to the flow sequence that would occur in an actual full size plant, provides data, which would be comparable to that in a full size treatment facility.

## Backwash Considerations

At the end of each filtration run, air and water were injected alternately into the bottom of the filter column over a period of time. For the pilot plant backwash operations, air volume was varied from 2.1 to 15.5 scfm/sq ft over 2.5 to 29 minutes for breaking up the "mud balls" which accumulated in the filter media. Then, air was stopped and backwash water was introduced to flush out all suspended solids until the filter media was clean and the backwash water effluent was observed to be clear.

Backwash water volume used ranged from 1.9 to 8.6 percent of the total combined sewer overflow filtered (1970 data) with the median value at approximately 4 percent. The range of backwash water rate employed was 31 to 90 gpm/sq ft over 4 to 25 minutes of backwashing. Due to the "wall effect" in the pilot filter column and inaccurate control of backwash water as well as inefficient backwash outlet design, an excessive amount of wash water and air may have been required.

Well designed high rate filtration plants for steel mill wastewater treatment systems, normally utilize backwash water rates at 30 gpm/sq ft for 10 minutes and air at 6 scfm/sq ft for 2 minutes (20).

## Table 19

## EFFECT OF STORAGE ON FILTER INFLUENT
## (1970 TEST DATA)

| Run No. | Length of Run (Hours) | Suspended Solids (Ave.) Screen Eff. mg/l | Suspended Solids (Ave.) Filter Inf. mg/l | Suspended Solids (Ave.) Δ | Ave. BOD Screen Eff. mg/l | Ave. BOD Filter Inf. mg/l | Ave. BOD Δ | Ave. COD Screen Eff. mg/l | Ave. COD Filter Inf. mg/l | Ave. COD Δ | Ave. Settleable Solids Screen Eff. mg/l | Ave. Settleable Solids Filter Inf. mg/l | Ave. Settleable Solids Δ |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 4 SF | 2 | 390 | 417 | +27 | 160 | 172 | +12 | 300 | 350 | +50 | 4.8 | 4.2 | -0.6 |
| *5 SF | - | - | - | - | - | - | - | - | - | - | - | - | - |
| 6 SF | 8 | 138 | 144 | + 6 | 57 | 63 | + 6 | - | - | - | - | - | - |
| 7 SF | 7 | 210 | 236 | +26 | 43 | 54 | +11 | 155 | 150 | - 5 | 2.4 | 2.6 | +0.2 |
| *8 SF | - | - | - | - | - | - | - | 142 | 143 | + 1 | 2.1 | 2.8 | +0.7 |
| 9 SF | 9 | 133 | 121 | -12 | 80 | 74 | - 6 | - | - | - | - | - | - |
| 10 SF | 10 | 96 | 113 | +17 | 57 | 75 | +18 | 117 | 112 | -25 | 2.3 | 2.1 | -0.2 |
| 11 SF | 6 | 137 | 175 | +38 | 90 | 97 | - 7 | 198 | 200 | + 2 | 1.6 | 1.4 | -0.2 |
| **13 SF | - | - | - | - | - | - | - | 280 | 283 | + 3 | 2.5 | 3.2 | +0.7 |
| 14 SF | 6 | 74 | 85 | +11 | 53 | 64 | -11 | - | - | - | - | - | - |
|  |  |  |  |  |  |  |  | 146 | 133 | - 7 | 0.9 | 1.4 | +0.5 |

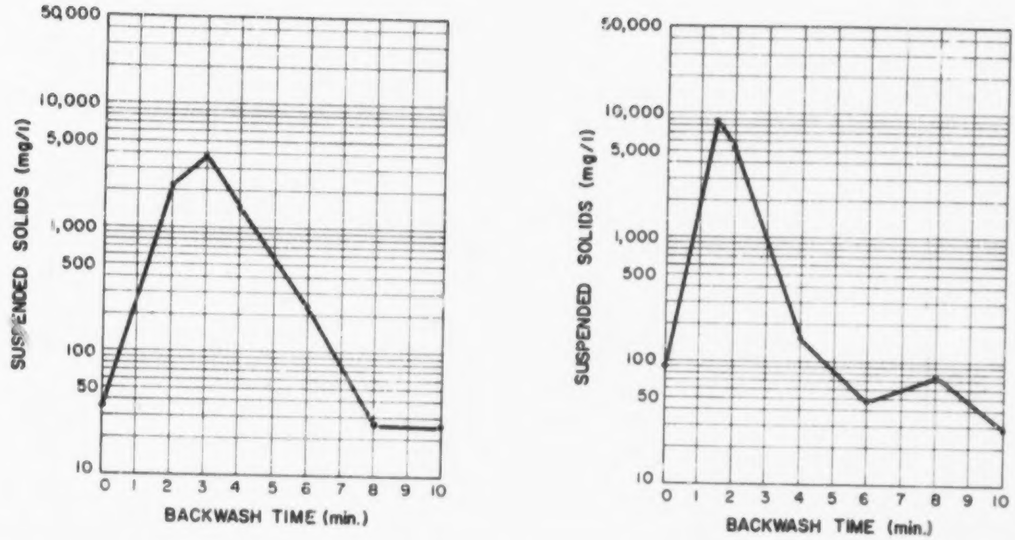
* - Insufficient Screen Data

** - Storage Tank Not Used

Figure 11 shows typical suspended solids profiles of backwash effluent water from various filtration backwashes. The effluent from the filter column was normally clear after 4 to 8 minutes of water flush. Suspended solids levels in the filter backwash water ranged between 50 and 14,000 mg/l.

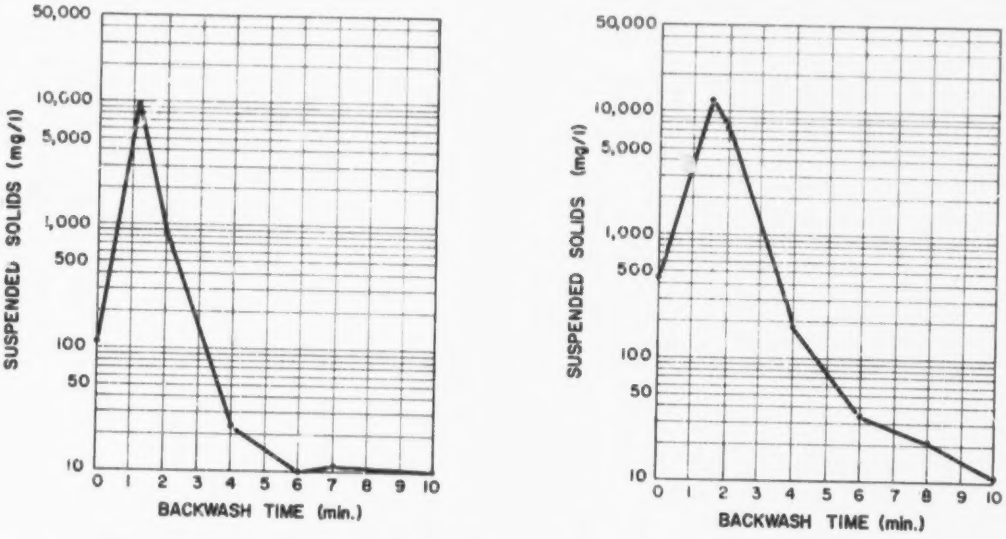
Figure [illegible] shows settling characteristics of filter backwash solids. The majority of suspended solids were removed at a test overflow rate of approximately 0.7 gpm/sq ft.

As indicated in Table B-3(Sheet Nos. 2 and 4) in Appendix B, a mass balance between solids removed during a filter run and solids contained in the filter backwash was developed. In most cases, a good correlation was not evidenced, probably influenced by the sampling procedure and the rapidly changing suspended solids levels in the filter backwash effluent.



FILTER BACKWASH FROM COLUMN RUN No. 4SF II

FILTER BACKWASH FROM COLUMN RUN No. 4SF III

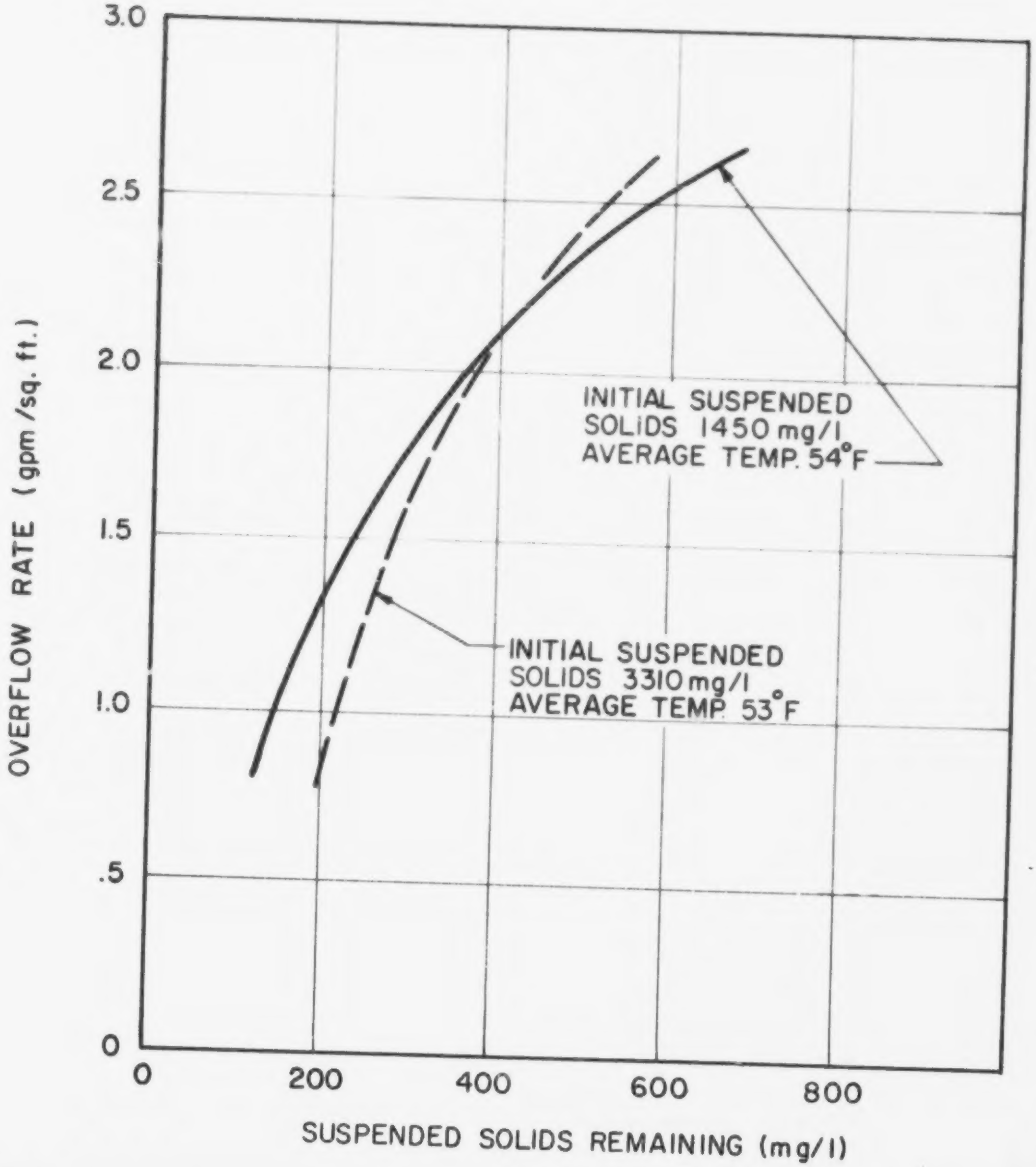


FILTER BACKWASH FROM COLUMN RUN No. 5SF II

FILTER BACKWASH FROM COLUMN RUN No. 5SF III

FILTER BACKWASH EFFLUENT
SUSPENDED SOLIDS Vs TIME

FIGURE 11



**BACKWASH WATER SEDIMENTATION CHARACTERISTICS**

FIGURE 12

# SECTION IX

## SYSTEM PERFORMANCE

The proposed treatment sequence is comprised of two treatment components, the screen facility and the high rate filters. Total system efficiency was determined by combining the efficiencies of these two treatment components. Where only filtration tests were performed, total system efficiency was determined by combining filtration removals and average screen removals from previous test runs.

The effect of the proposed treatment system (No. 40 mesh screen and high rate filters with No. 3 Anthracite over No. 612 Sand) in regard to the removal of key water quality parameters is presented in Figures 13 to 15 and Tables 20 through 22.

During the screening-filtration system operation, process efficiency varied with influent suspended solids concentration, whereas the effluent concentration remained comparatively constant (21). The following table shows the results of suspended solids removal from a typical combined sewer overflow filtration test with 30 mg/l of alum and 1.0 mg/l of polyelectrolyte addition. With effluent suspended solids of 36 mg/l, the removal efficiency would be 92 percent at the initial period of combined sewer overflow when suspended solids concentrations are about 442 mg/l, whereas the reduction of suspended solids would be only 46 percent after the peak overflow period when the influent concentration is 100 mg/l and the effluent concentration is 54 mg/l.

| Filtration Rate (gpm/sq ft) | Number of Samples | Average Influent S.S. (mg/l) | Average Effluent S.S. (mg/l) | Removal (%) |
|---|---|---|---|---|
| 8 | 3 | 442 | 36 | 92.0 |
| | 2 | 362 | 48 | 86.7 |
| | 2 | 100 | 54 | 46.0 |
| 16 | 3 | 442 | 82 | 81.5 |
| | 2 | 362 | 60 | 83.5 |
| | 2 | 100 | 64 | 36.0 |

Figure 13 shows the effect of filtration rate upon the removal of suspended solids, including the effect of polyelectrolyte on process efficiency. Without chemicals, tested in 1970, suspended solids removals ranged from 40 percent (average of 22 grab samples in 2 filter runs) at a filtration rate of 40 gpm/sq ft, to 77 percent (average of 8 grab

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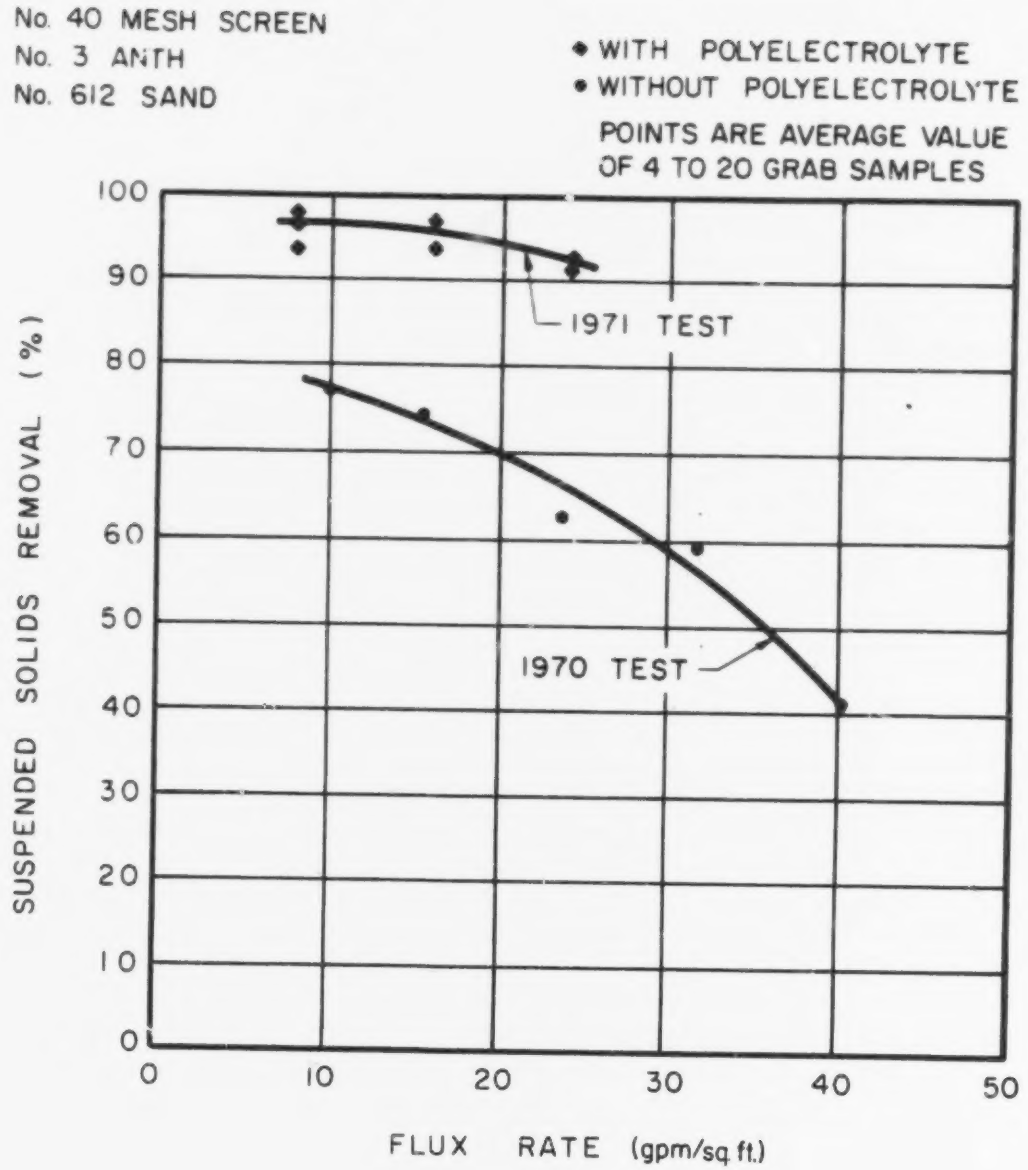


SYSTEM PERFORMANCE

SUSPENDED SOLIDS REMOVAL

FIGURE 13

samples in one filtration) at a filtration rate of 10 gpm/sq ft with an influent suspended solids concentration range of 160 to 190 mg/l. With the addition of an appropriate polyelectrolyte (1 mg/l) tested in 1971, suspended solids removal efficiencies significantly improved, ranging from 91.6 percent (average of 6 grab samples) at a filtration rate of 24 gpm/sq ft to 97.7 percent (average of 6 grab samples) at a filtration rate of 8 gpm/sq ft at an average influent suspended solids concentration of 250 to 400 mg/l. With polyelectrolyte addition, process efficiency is substantially the same at 24 gpm/sq ft as it is at 8 gpm/sq ft although, as indicated in the previous chapter, head loss build-up is significantly greater at 24 gpm/sq ft.

Settleable solids removals by the screening-filtration process are indicated on Table 20. For all filtration rates tested, settleable solids removal generally falls within the range of 80-90 percent. Without polyelectrolyte addition, for filtration rates of 16 gpm/sq ft at an average influent level of 5.8 ml/l, removals are in excess of 94 percent. With the addition of polyelectrolyte and an average influent level of 8.8 ml/l, system removals of settleable solids are in excess of 98 percent for filtration rates of 24 gpm/sq ft. Probably the most significant fact from this table is that settleable solids removals are substantially increased at 24 gpm/sq ft with the addition of polyelectrolyte. The proposed system, with polyelectrolyte addition, essentially removes all of the settleable material.

Table 20

SYSTEM PERFORMANCE

SETTLEABLE SOLIDS REMOVALS

| Filtration Rate (gpm/sq ft) | Number of Samples | Average Influent (ml/l) | Average Effluent (ml/l) | Removal (%) |
|---|---|---|---|---|
| Plain (1970) | | | | |
| 10 | 12 | 5.1 | .07 | 98.5 |
| 16 | 13 | 5.8 | .35 | 94.1 |
| 24 | 8 | 5.8 | .67 | 88.5 |
| 32 | 5 | 3.2 | .51 | 85.0 |
| 40 | 8 | 5.1 | .4 | 90.5 |
| With Polyelectrolyte (1971) | | | | |
| 8 | 6 | 5.8 | .1 | 98.3 |
| 16 | 6 | 4.8 | .1 | 97.9 |
| 24 | 6 | 8.8 | .13 | 98.6 |

Removal efficiencies for BOD are presented in Table 21. This table shows a wide range of BOD removals for process performance at various filtration rates. Without polyelectrolyte addition at filtration rates of 24 and 16 gpm/sq ft, BOD removals ranged from 39.5 to 53.2 percent at an influent concentration of 72 mg/l. With the addition of polyelectrolyte, improvement in BOD removals are evidenced, 65.9 to 78.7 percent at rates of 24 and 8 gpm/sq ft for an influent concentration of 74.4 mg/l.

Table 21

SYSTEM PERFORMANCE

BOD REMOVALS

| Filtration Rate (gpm/sq ft) | Number of Samples | Average Influent (mg/l) | Average Effluent (mg/l) | Removal (%) |
|---|---|---|---|---|
| Plain (1970) | | | | |
| 10 | 13 | 90.0 | 49.0 | 43.8 |
| 16 | 14 | 72.0 | 40.0 | 53.2 |
| 24 | 8 | 72.0 | 49.0 | 39.5 |
| 32 | 6 | 67.8 | 52.0 | 23.4 |
| 40 | 8 | 90.0 | 49.0 | 49.8 |
| With Polyelectrolyte (1971) | | | | |
| 8 | 6 | 74.4 | 27.0 | 78.7 |
| 16 | 6 | 74.4 | 27.5 | 63.5 |
| 24 | 6 | 74.4 | 31.3 | 65.9 |

As can be seen from Table 22, COD removals also exhibit a wide range of values, with high removals for the mode of operation using polyelectrolyte addition. The range of both BOD and COD removals obtained from the pilot tests showed that this process could not be expected to reduce the dissolved organic contaminants in combined sewer overflows. Furthermore, due to the industrial component in the wastewater flow to the Southerly Wastewater Treatment Plant, BOD and COD removals are probably related as much to the nature of the flow on that particular day as they are to the efficiency of suspended solids removals.

## Table 22

## SYSTEM PERFORMANCE

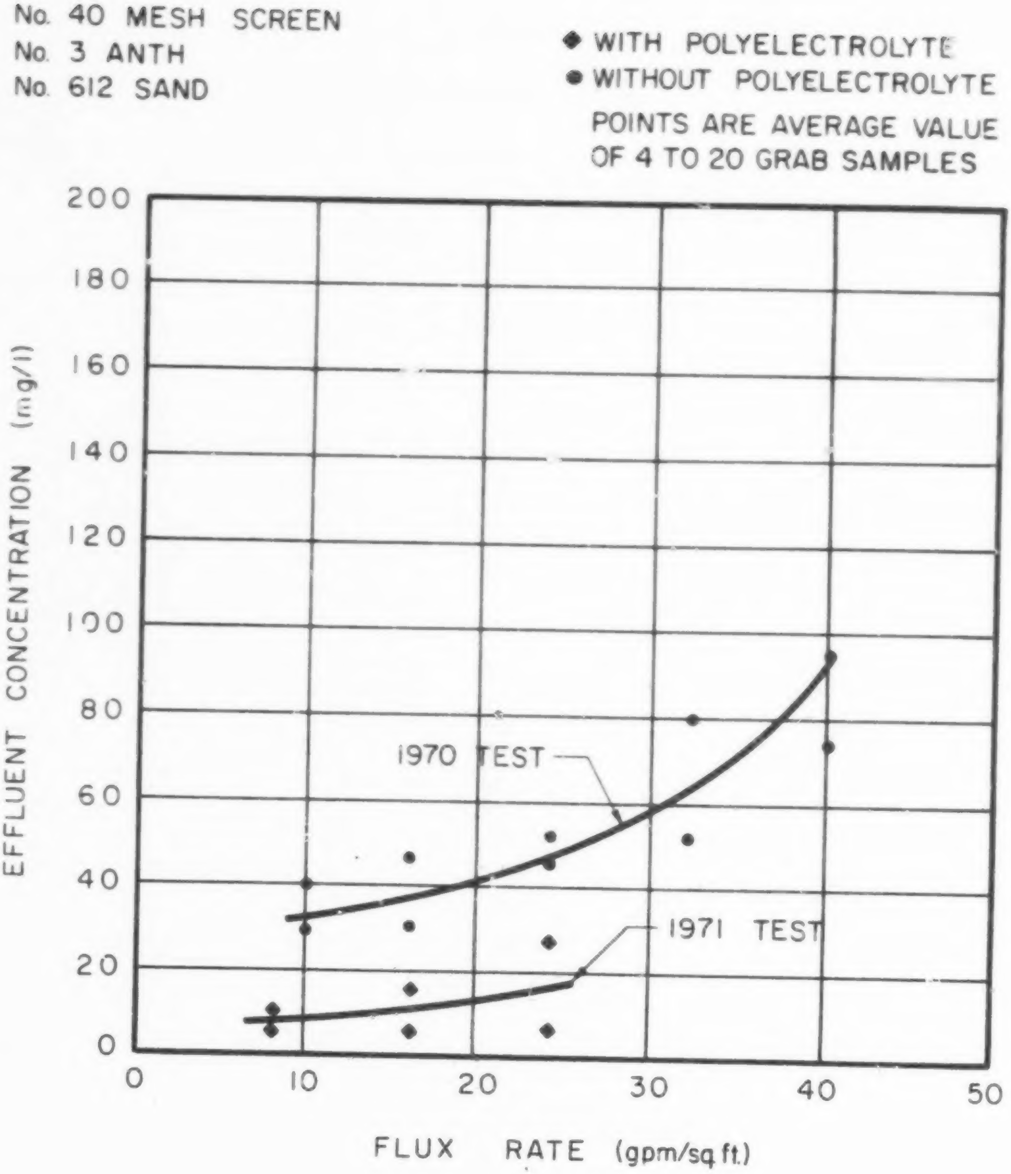
## COD REMOVALS

| Filtration Rate (gpm/sq.ft.) | Number of Samples | Average Influent (mg/l) | Average Effluent (mg/l) | Removal (%) |
|---|---|---|---|---|
| Plain (1970) | | | | |
| 10 | 13 | 188.0 | 44.0 | 72.5 |
| 16 | 5 | 303.3 | 136.0 | 58.8 |
| 24 | 6 | 483.0 | 228.0 | 59.6 |
| 32 | 6 | 213.0 | 49.0 | 77.0 |
| 40 | 4 | 188.0 | 83.0 | 56.5 |
| With Polyelectrolyte (1971) | | | | |
| 8 | 6 | 208.9 | 44.5 | 78.7 |
| 16 | 6 | 201.4 | 73.5 | 63.5 |
| 24 | 6 | 206.7 | 70.5 | 65.9 |

As indicated in the previous section, total phosphate removals by the screening-filtration process, with polyelectrolyte addition, are in the order of 30 to 80 percent. The amount of phosphate removal is related to that percentage of total phosphate which is in the suspended form, and amenable to removal by filtration.

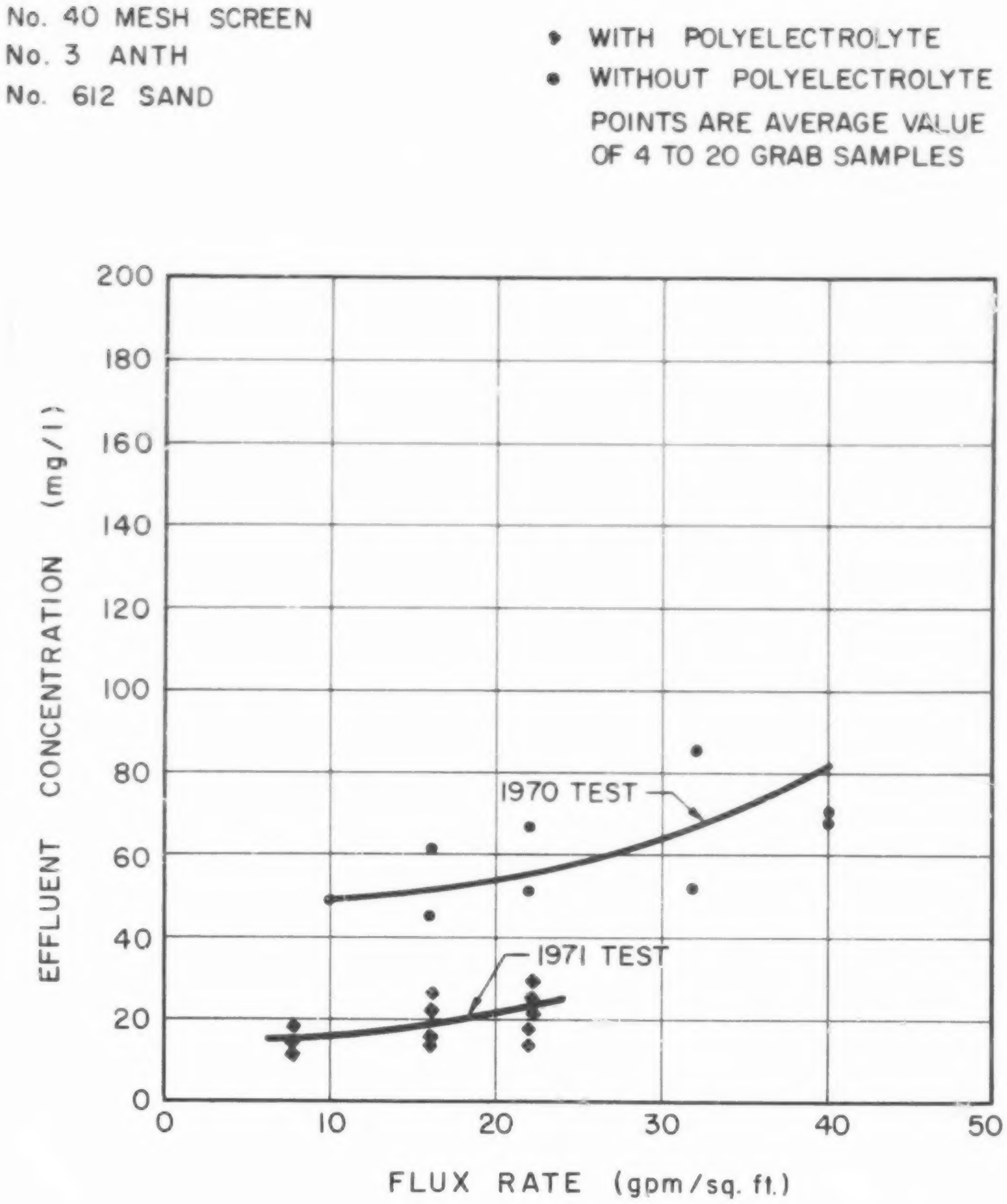
Fecal coliform removals, as shown in Table B-1, in Appendix B, exhibit a wide range of values. Removals generally lie in a span between 14.6 to 87.6 percent with an influent range of 4.3 to 20.7 x $10^6$/100 ml. reduced to 2.1 to 4.8 x $10^6$/100 ml. in the effluent. This is insignificant for disinfection purposes. A further disinfection process should be added in conjunction with the screening-filtration system. Fecal coliform data presented on this table is based on 1970 test work, which was prior to the system optimization through polyelectrolyte addition.

Figures 14 and 15 show effluent suspended solids and effluent BOD levels for various test runs, relating effluent quality levels to filtration rate.



SYSTEM PERFORMANCE
EFFLUENT SUSPENDED SOLIDS QUALITY

FIGURE 14



SYSTEM PERFORMANCE
EFFLUENT B O D QUALITY

FIGURE 15

The recommended system is a drum screen (No. 40 mesh screen element) followed by a deep bed, dual media filter (five feet of No. 3 anthracite over three feet of No. 612 sand). Polyelectrolyte feed is an essential and critical part of the system to achieve optimum treatment efficiencies. Data utilizing coagulants ahead of filtration (contained in the previous chapter) showed inconsistency in treatment efficiencies and at the present stage of development, polyelectrolyte feed alone appears optimum.

To summarize, the proposed system, with addition of appropriate polyelectrolyte, achieved the following treatment performance:

| Filtration Rate (gpm/sq ft ) | Average Removals (%) | | |
|---|---|---|---|
| | Suspended Solids | BOD | Phosphorus |
| 8 | 96 | 43 | 66 |
| 16 | 95 | 40 | 57 |
| 24 | 93 | 40 | 46 |

The average influent suspended solids concentration ranged 50 to 500 mg/l and the average influent BOD concentration ranged from 30 to 300 mg/l. Effluent levels at 24 gpm/sq ft with polyelectrolyte addition were 15 mg/l suspended solids and 22 mg/l BOD, respectively.

# SECTION X

## DEFINITION OF HIGH RATE FILTRATION INSTALLATIONS

### General Considerations

The solution to a community or a municipality's problem of pollution caused by combined sewer overflows will probably be resolved, in most cases, through a combination of approaches. The first would be maximization and utilization of the storage capacity of the sewer system, and its proper regulation, to minimize overflow frequencies and volume. Another alternative would be to construct storage facilities which could detain the high volume, short duration discharges of combined sewer overflows, and return them to a municipal sewage treatment facility or to a specially designed combined sewer overflow facility. A third possibility would be to pass the combined sewer overflow directly through a high rate treatment process such as the system under study in this research project. These alternatives or potential solutions could be incorporated and utilized together to form a composite combined sewer overflow pollution control program. Sewer separation is not considered, in general, to be a realistic alternative approach (15).

The test results and the mode of test operation are indicative of treatment efficiencies and effluent levels that could be achieved by passing combined sewer overflow discharges directly through the proposed treatment system. Thus, the nature of the flow to a proposed screening-filtration treatment process would be one of a variable nature. Depending upon the overflow hydrograph that would result from particular combined sewer overflows, the flow to the plant could change slightly or change very drastically. This, of course, would be related to the type of downpour experienced and also to the extent of the drainage area served by the combined sewer overflow facilities. For example, in small areas, the combined sewer overflow hydrograph would peak very sharply after initial rainfall. For larger systems, that is serving extensive areas, the hydrograph would probably be flatter and peak at a slower rate. Under these conditions, it would be more realistic to consider a high rate treatment process to handle combined sewer overflows. In other words, the proposed process is more applicable to areas where sewer lag times and other factors tend to flatten out the combined sewer overflow hydrograph such that the treatment facility would not be subject to an immediate hydraulic shock load.

Due to the nature of combined sewer overflow, that is, a short duration, high flow volume discharge, it appears likely that, in many cases, storage will be incorporated into the overall system or scheme to control pollution from combined sewer overflows. The economics, desirability, and merits of storage preceeding high rate filtration would have to be specifically and individually evaluated for each particular case. For example, if a large storage facility was provided ahead of the filtration plant, it would probably be possible to utilize a smaller filtration plant to accommodate the combined sewer overflow discharge over a longer period of time. If storage facilities are provided, consideration must be given to returning the greatest portion of the detained combined sewer overflow to the municipal treatment plant, after the combined sewer overflow has terminated.

In regard to treatment efficiencies, it is not envisioned that a substantial improvement in process performance could be achieved if storage was provided ahead of a filtration facility. As regards overall system costs, trade-off values between straight line treatment through a high rate filtration facility versus storage and treatment of the combined sewer overflow through a smaller filtration plant cannot be effectively evaluated in a general case due to the variable nature of storage costs.

## Straight Line Treatment of Combined Sewage Storm Overflows

In developing conceptual design and cost data for the high rate filtration process to treat combined sewer overflow, a straight line treatment system has been assumed. That is, the combined sewer overflow would be directed to the filtration plant, without any intermediate storage step. No marked improvement in treatment efficiencies can be achieved by storage ahead of the filtration process and, in addition, this process seems most suitable for metropolitan communities, where space and costs limitations would preclude significant storage facilities. The filtration facility would be sized to treat a certain peak volume of combined sewer overflow, which would, in turn, be determined from a study of combined sewer overflow hydrographs from a defined drainage area. In other words, all overflows in volume equal to or less than the design capacity of the filtration plant would be handled directly. Selection of this design hydrograph for sizing the filtration facility would require an evaluation of water quality levels desired, the probability of overflows occurring in excess of the treatment capacity at the filtration plant, and the general degree of water quality control required.

One possible way to accommodate instantaneous combined sewer overflow peaks in excess of the capacity of the treatment facilities would be to provide storage for this high flow, short duration excess. In terms of total combined sewer overflow volume, the bulk of the combined sewer overflow would pass directly through the high rate treatment process, that is, the filtration plant, and a small portion of the total volume, as a percent, would be collected in smaller storage facilities. After the termination of the combined sewer overflow, the water collected in the storage facilities could be returned to the municipal sewage treatment plant, or directed to the high rate filtration facilities. Of course, selection of plant capacity to treat combined sewer overflows at a particular location, in essence, depends on a selection of a "design" combined sewer overflow hydrograph based on cost-water quality benefit analyses. Also, the decision to provide storage for instantaneous flow volumes in excess of plant capacity is one which would be determined after a cost-water quality benefit analysis.

## Process Sequence

Based on the results of the testing program, a conceptual schematic of the proposed high rate filtration system for the treatment of combined sewer overflows is presented in Figure 16. Combined sewer overflows would be conveyed from an automated overflow chamber, or chambers (in case the centralized filtration system is for many overflow points), to a low lift pump station. Before entering the pumping station, the combined sewer overflow would pass through a bar rack (screen) for removal of coarse materials which might cause problems in the operation, maintenance or wear of the low lift pumps. In certain locations, where consistent with local topography and sewer invert, a low lift pumping facility may not be required.

The combined sewer overflow from the low lift pump station would enter a treatment building and be delivered to drum type screening units. The wastewater would be introduced into the center of the drum type screen and would pass through the screening mesh into the influent channel to the filters. As indicated previously, a gravity type design, that is, open filtration units, are proposed. The water would be introduced at the top of the filter and flow downward through the filter bed. The plant effluent could be discharged by gravity to the respective receiving water body.

Filtered wastewater would serve as a source of water for backwashing filters after the overflow has attenuated to a sufficient degree. The filteration building would be provided with low pressure air blowers as a source of backwash air. Backwash pumps would be located in the filtration facilities to deliver water to the filters for backwashing. The

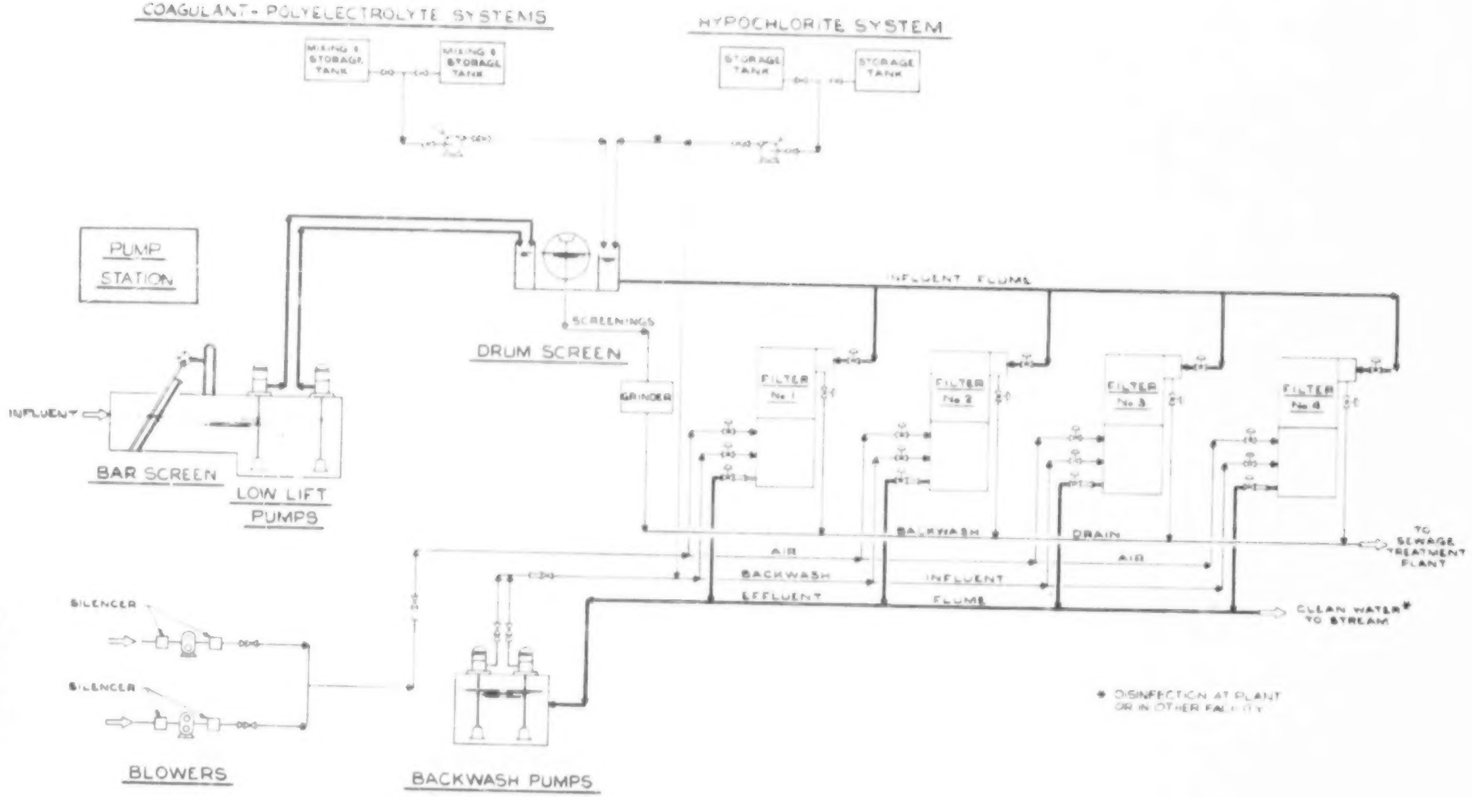


FIGURE 16

HIGH RATE FILTRATION INSTALLATION PROCESS FLOW DIAGRAM treatment building would also include a control area, office space, a polyelectrolyte feeding set-up, and a system for adding hydrochlorite to filter backwash water for the prevention of slime growth on the filter media. The operation of the high rate filtration facility would be completely automated, and could be left unattended, except for routine maintenance and periodic delivery of chemicals. In full size treatment systems, chlorine feed for disinfection could be incorporated into the filtration facilities.

Dirty backwash effluent from the filtration facilities and screenings would be directed into the interceptor running to the sanitary sewage treatment facility. The concentrated solids from the drum screening units would be passed first through a grinder, and then through a trash basket or classification device to insure that very coarse, settleable material is not returned to the sewer system. Sludge handling facilities should not be located at the filtration site, as this would prove very costly. Centralization of material handling facilities has always proved most economical; as an example, the Southerly Wastewater Treatment receives sludges from another plant in Cleveland.

Under most conditions of treating combined sewer overflow, it would be possible to backwash the filters after the storm is over. For situations where a continuous overflow lasts for many hours, two backwash handling possibilities appear feasible: first, since the filtration facilities are located above grade, it is probable that the backwash from the filtration plant could be discharged downstream of the combined sewer overflow point. This could be accomplished by utilizing the available static head (water level) in the filtration plant, even though this portion of the combined sewer would probably be flowing full. Another more remote possibility would be to return the filter backwash effluent to the combined sewer upstream of the overflow point. Under this alternate, a certain percentage of backwash solids would be transported to the sewage treatment facility and the remainder to the filtration plant. The rationale behind this second alternate is that when backwash is required, it would probably be in the latter stages of a storm when the flow volumes and solids levels entering the filter plant would be reduced. Therefore, the filter plant could probably accept the additional solids material and flow without any major problem.

To insure smooth operations even in areas with rather mild sewer slopes, the material from the screening unit, as shown in Figure 16 is passed through a grinder to minimize solids size, before being discharged with the filter backwash into the combined sewer. Since the proposed screening filtration system would normally be preceeded by a low lift pumping facility equipped with a traveling screen (rack), coarser materials, which could possibly cause sedimentation problems in combined sewers having flat or mild slopes, would be probably removed at the screening unit. The nature of the material discharged from the proposed filtration system in the filter backwash would not cause any serious problems of deposition in the combined sewer systems. Also, the intermittent flushing nature of the backwash flow would tend to disturb any accumulated solids in these sewers.

## Mode of Operation

The flow to the filtration facility for treating combined sewer overflows would be of a variable nature. It would gradually build up, then reach a hydraulic peak, and then recede gradually. Two possible methods of operation appear feasible. One method of operation, as is proposed for a flotation system in the treatment of combined sewer overflows (22), would be to operate the filtration units in sequence, based on design flow rate. If a filtration plant had 8 filters designed to accomodate 100 MGD, or a design rate of 12.5 MGD per filter, they would be operated, in turn, as the flow built up. For example, if an overflow was 12.5 MGD, only one filter would be operating, and as the flow built up higher, additional filters would be turned on after the design rate of the filters in operation was exceeded. The operating unit would remain on line and function at decreasing filtration rates as the filter bed became gradually clogged until filter head loss reached a preset value. The filter would then be ready for backwashing. Filtration rate declining from a maximum value to lesser values does not appear to be cause for any concern, as this practice is utilized in many water treatment plants (23), where filters are initially run at high rates, and then as the head loss builds up within the filter, the rate is decreased and less water is filtered. Actually, it has been reported that this mode of operation, commonly referred to as "declining rate filtration" in the potable water treatment field, results in a better quality effluent than operating at a constant rate for the duration of the filter run.

An alternate method of filtration would be to equally divide whatever flow enters the filtration facility among the various filter units. This is the flow control system that has been successfully utilized in a gravity industrial wastewater treatment plant in the Midwest (10). In effect, at the beginning of the combined sewer overflow, each filter unit would probably be operating below design rate, and as the storm progressed the filtration rate on each unit would build and approach the design loading, depending on the volume of the combined sewer overflow. After the hydraulic peak, the filtration rate on each filter unit would decrease as the storm overflow subsided. This second mode of operation would be accomplished by flow indicators and controllers on the effluent end of each filter unit. Essentially, each filter unit flow indicator sends a signal to a central controller, which sums up all flow signals from all filters, divides the flow signal by the number of units, and returns a signal to each individual filter controller, assigning each individual unit its respective percentage of the flow.

In regard to the second mode of operation, some legitimate questions may be raised as to whether solids removed at low filtration rates during the early stages of the combined sewer overflow will be sheared off and would show up in the effluent from the filter during operation of the filter at peak flow rates and filtration rates.

The overall percent reductions of suspended solids experienced during a combined sewer overflow in a full size facility would be greater than evidenced from the constant-flow test work (see Figure 8) due to the effect of reduced filtration rates as the storm flow subides. If it is workable, the second mode of operation might provide a greater overall percent reduction of contaminants by maintaining minimum filtration rate for the entire combined sewer overflow. The optimum method of operation can only be conclusively verified through actual operation in a demonstration plant or full sized facility.

It must be mentioned, however, that after the hydraulic peak of the overflow occurs (design for peak at 24 gpm/sq ft), the flow to the filtration facility would decline. When evaluating and translating test data into design parameters, it must be remembered that the filtration rate of a plant would decline after the hydraulic peak of the sewer overflow was reached, and as such, constant flow test work parameters cannot be directly applied to engineering designs, without considering the nature of the process operation, that is, filtering at varying rates throughout the duration of the sewer overflow.

For filter backwashing, two types of process control should be considered: the first parameter would be total head loss through filter bed and the second would be effluent suspended solids concentration.

For measuring the filter head loss, each filter would be equipped with a differential pressure transmitter to continuously sense the loss of head across the filter and transmit a pneumatic signal linearly proportionate to this head loss to a central control panel. When the filter head loss would reach a preset value, the differential pressure switch associated with the filter would be actuated. A contact in this switch would open in a stepping switch circuit and the filter would start to backwash.

An alternate filter backwash control could be achieved with an effluent suspended solids monitor. A continuous reading, light scatter type suspended solids meter would be installed in each filter effluent pipe to continuously measure the suspended solids concentration and transmit the reading to a recorder at a central control panel. When the filter breakthrough would suddenly take place and the suspended solids concentration indicator would reach a preset level, then a micro switch would be activated and an alarm would be initiated. The operator would check the filter performance condition and start to backwash the filter.

## Solids Handling Aspects

As indicated previously, the backwash from the filtration plant and the material removed by the 40 mesh screening units should be delivered to the sanitary sewerage system for subsequent treatment. Insofar as the high rate filtration installation would be designed as a highly automated, unattended facility, the solids or sludge from this proposed wastewater treatment system should be handled at another location, specifically the nearest municipal sewage treatment plant.

If, for some reason, delivering the backwash into a sewer carrying wastewaters to a municipal wastewaters plant were not feasible, some intermediate form of solids compaction and dewatering could be incorporated into the proposed high rate filtration treatment system. One possibility would be to provide settling basins for the filter backwash, which would remove backwash solids from the backwash water. The overflow from these basins would be directed or returned into the filtration facility. The compacted underflow could be pumped to the nearest combined sewer which would carry the sludge material to the sewage treatment plant. The sludge volumes that would result from treatment of a significant discharge are such that trucking of compacted sludge seems to be a remote and very unlikely possibility.

Taking the solids handling process one step further, in addition to providing backwash sedimentation and compaction basins at the filtration site, solids dewatering facilities could also be provided. Assuming that this sludge material would have dewatering properties as good as primary sewage, the sludge could be handled by vacuum filter or centrifuge to produce a desirable dewatered cake. The dewatered cake would have to be conveyed by truck to an appropriate incineration plant of the nearest sewage treatment plant for final disposal. If ultimate disposal of solid materials removed from combined sewer overflows was required at the treatment site, some type of incineration process could probably be utilized. As the solids handling aspects of a proposed combined sewer overflow treatment process becomes more involved and complicated, so does the project cost and the effort in manpower that is required to handle these facilities. Further study of backwash sludge characterization, such as sludge density, biodegradability, nutrient content, methods of dewatering and final disposal of the sludge should be taken into consideration.

The proposed treatment system, equipped with backwash sedimentation basins, could function as an automated and unattended treatment facility, which is desirable considering the nature and application of the proposed system. If additional solids handling and processing facilities were to be incorporated into the proposed treatment system, it is unlikely that the facility could be left unattended and the overall treatment process would become much more expensive.

## Conceptual Design

A full evaluation and study of a proposed treatment system requires that conceptual engineering work be developed in order to define, determine and evaluate integral elements of the treatment system, and to provide a basis for developing some realistic cost figures. Also, physical details and arrangements of any proposed treatment installation are important in determing whether or not the "public acceptance factor" would be favorable for such a treatment facility. Certain processes and waste treatment systems can be housed and arranged economically so that they can be located in many areas without public outcry for architectural, aesthetic or environmental reasons. For example, trucking of sludge solids from a treatment facility or exhaust gases and particulates from a sludge incinerator might cause public opposition.

For conceptual design purposes, the low lift pumping facility and the treatment plant have been incorporated into one site. Centralization and integration of pumping and treatment facilities is generally desirable, although in many cases it is not feasible. For example, land availability, sewer invert, topography, and a number of physical factors may make this situation uneconomical or unfeasible. In addition, a centralized high rate filtration installation to accommodate combined sewer overflow discharges from various overflow points may receive flows from a number of pumping stations located at different points throughout the combined sewer system.

A slab on grade type construction is assumed for conceptual design purposes. For the treatment portion of the system this is a realistic assumption, although determining the features of a low lift pump station is very uncertain, particularly due to an assumed sewer invert. As shown in the following section on cost data, the evaluation of the treatment plant is considered separately from the pumping facility, since integrating low lift pumping costs with treatment costs is not an accurate or efficient approach. Pumping and wastewater conveyance costs are too variable to be considered in terms of developing generalized cost data for a particular process or treatment system.

In developing generalized conceptual designs, effort has been centered on plant sizes ranging from 25 to 200 MGD design capacity. This range covers most area of potential application and provides a sufficient basis for evaluating the merits and cost-efficiency factors of a high rate filtration system. As a general order of magnitude reference, a 200 MGD filtration facility could accommodate the flow from a 96-inch diameter sewer.

Treatment plant features are delineated and defined on Figures 16 through 23. The facilities shown are designed for filtration rate of 24 gpm/sq ft, with polyelectrolyte addition for optimum suspended solids removal. These particular wastewater treatment facilities would be capable of hydraulically accepting an additional wastewater volume of approximately 20 percent greater than the design rate of the plant. As in most, or normal, wastewater treatment designs, plant hydraulic capacity is generally set somewhat higher than the plant capacity dictated by process considerations.

As shown in Figure 16, which was discussed earlier, the major units of the proposed treatment system includes drum screens and high rate filters. Additional features include: backwash pumps, backwash air blowers, which are also essential to the process operation. A polyelectrolyte system and a hypochlorite system are also incorporated into the treatment plant. Polyelectrolyte will provide for optimum plant operation in regards to removal efficiencies. The hypochlorite system is required to disinfect the backwash water so that slime growths do not occur in the filter media. This system could also be utilized, if properly sized, to provide chlorine for disinfection of the combined sewer overflow. Low lift pumping facilities and a bar screen for pump protection are also shown on this drawing. Depending on the nature and application in each particular area, the bar screen and low lift pumps might be located at a site far removed from the plant.

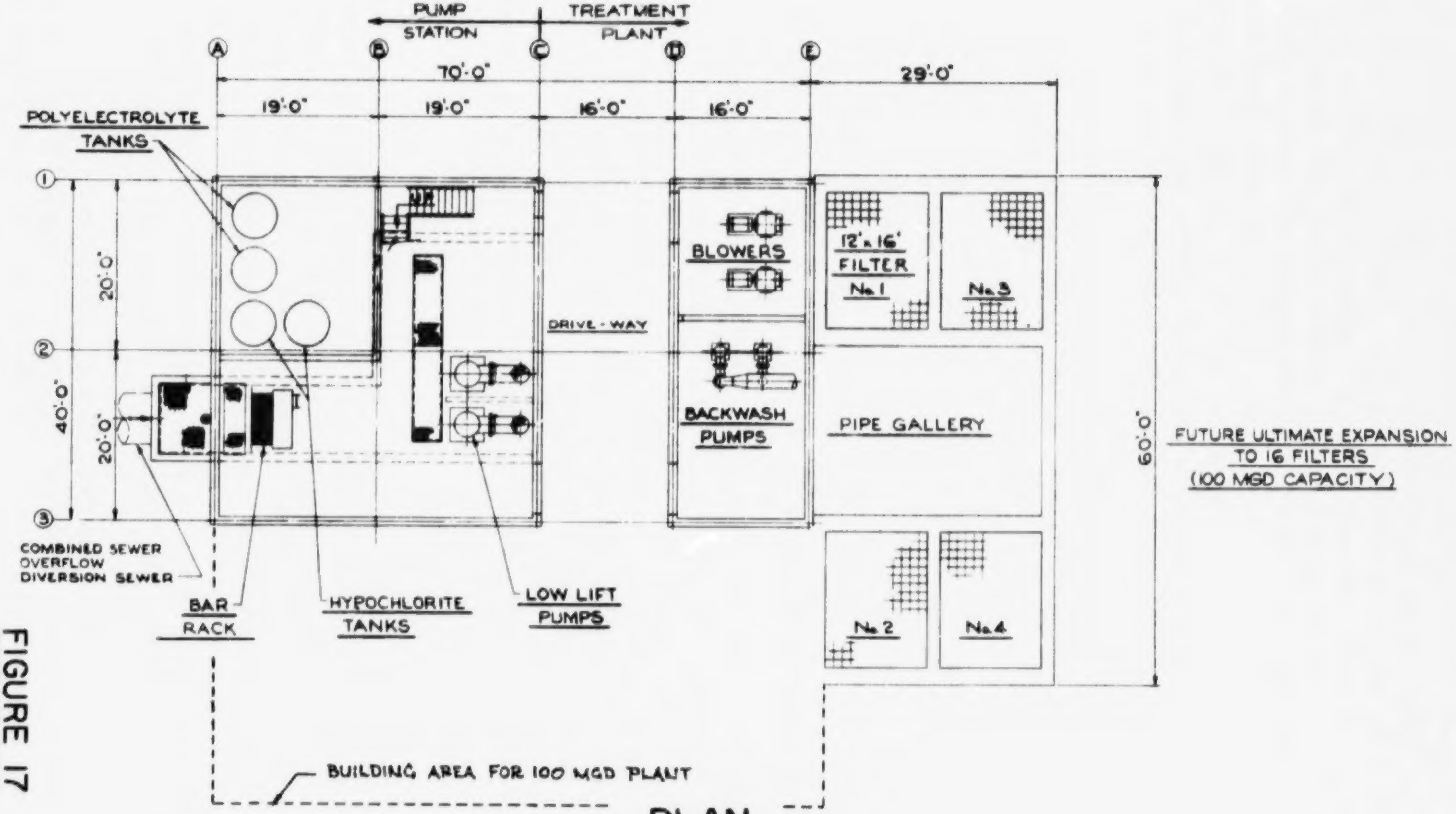
Figures 17 and 18 show general arrangements for filtration plants designed to accommodate 25 and 50 MGD of combined sewer overflow. The same basic arrangement or module is used in developing both of these plants. For example, the major difference between the 50 MGD plant and the 25 MGD plant is that additional filters and drum screens are added, while the basic arrangement and features of the facilities remain the same. This basic treatment arrangement or module can be developed up to a capacity of 100 MGD, as shown on both of these drawings. The ultimate development of this treatment module would include 16 filter units, each filter being 12 feet by 16 feet.

As shown in Figure 19, the facility consists of three basic areas. Starting from left to right on the drawing, the first portion of the proposed facility can be described as a pumping station, housing low lift pumping units and a bar rack (screen), to lift combined sewer overflows into the treatment plant. The second area, or head end of the treatment plant, houses the drum screen units, which treat the flow prior to entering the filters. These two areas are normally referred to as the control building portion of the high rate filtration installation. The third section of this facility contains the high rate filtration units, which are the major treatment elements.

As indicated in these figures, the facility arrangements and equipment layouts cannot be described as skimpy, and are the type of arrangements that would be required in many large municipal plants. Referring to these figures, the first level in the control building portion of the treatment facility includes the variable speed low lift pumping installation, the bar rack (screen), the chlorine and polyelectrolyte feed equipment, and the backwash pumps, which extract their source of water from the plant effluent. The upper level of the plant includes the drum screening units, electrical and control areas, and space allocations for office, service areas, etc.

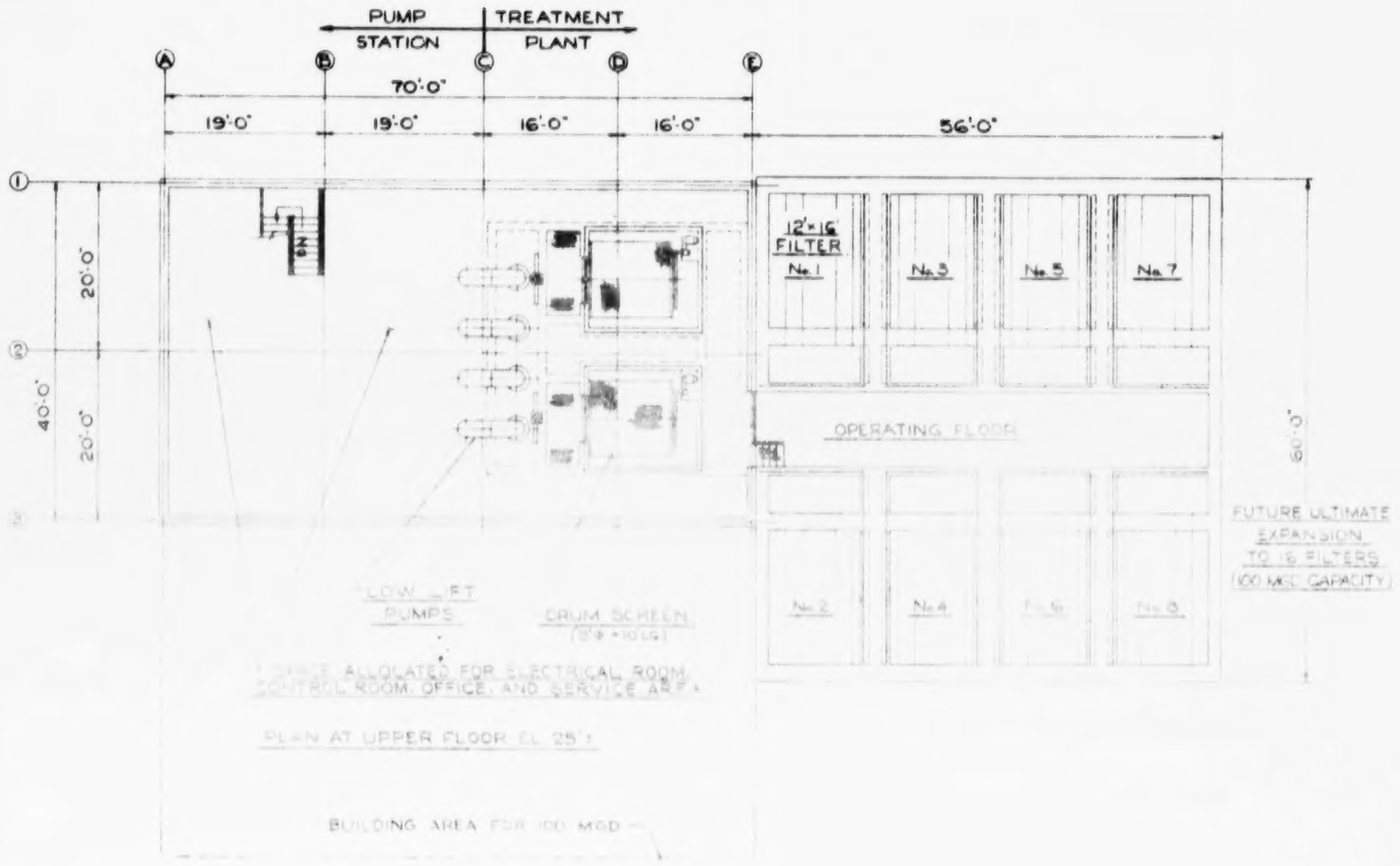
Briefly, the flow sequence begins with the combined sewage storm overflow being conveyed by gravity to the treatment facility. It first passes through a bar rack (screen) for removal of coarser materials which might impede pump operation. The combined sewage storm overflow is then directed by the low lift pumps up to a central distribution channel, whence the water is fed by gravity to the rotating drum screening units. The water enters the center of the screens and flows outward through the circumference. Solids are retained on the screen surface and as the retained solids reach the top or highest point on the screening circumference, they are removed by high pressure water sprays. The screened effluent than flows by gravity into a central filter influent flume. The water is distributed into each of the high rate filters, and subsequently, after filtration, is discharged by gravity to an effluent sewer.

FIGURE 17



PLAN

HIGH RATE FILTRATION INSTALLATION - 25 MGD CAPACITY


PUMP STATION
TREATMENT PLANT
A
B
C
D
E
70'-0"
19'-0"
19'-0"
16'-0"
16'-0"
56'-0"
1
2
3
20'-0"
20'-0"
40'-0"
60'-0"
12'×16' FILTER
No. 1
No. 3
No. 5
No. 7
No. 2
No. 4
No. 6
No. 8
OPERATING FLOOR
FUTURE ULTIMATE EXPANSION TO 16 FILTERS (100 MGD CAPACITY)
LOW LIFT PUMPS
DRUM SCREEN (8'⌀ × 10' LG)
SPACE ALLOCATED FOR ELECTRICAL ROOM, CONTROL ROOM, OFFICE, AND SERVICE AREA
PLAN AT UPPER FLOOR EL 25'±
BUILDING AREA FOR 100 MGD

PLAN

HIGH RATE FILTRATION INSTALLATION - 50 MGD CAPACITY

FIGURE 18

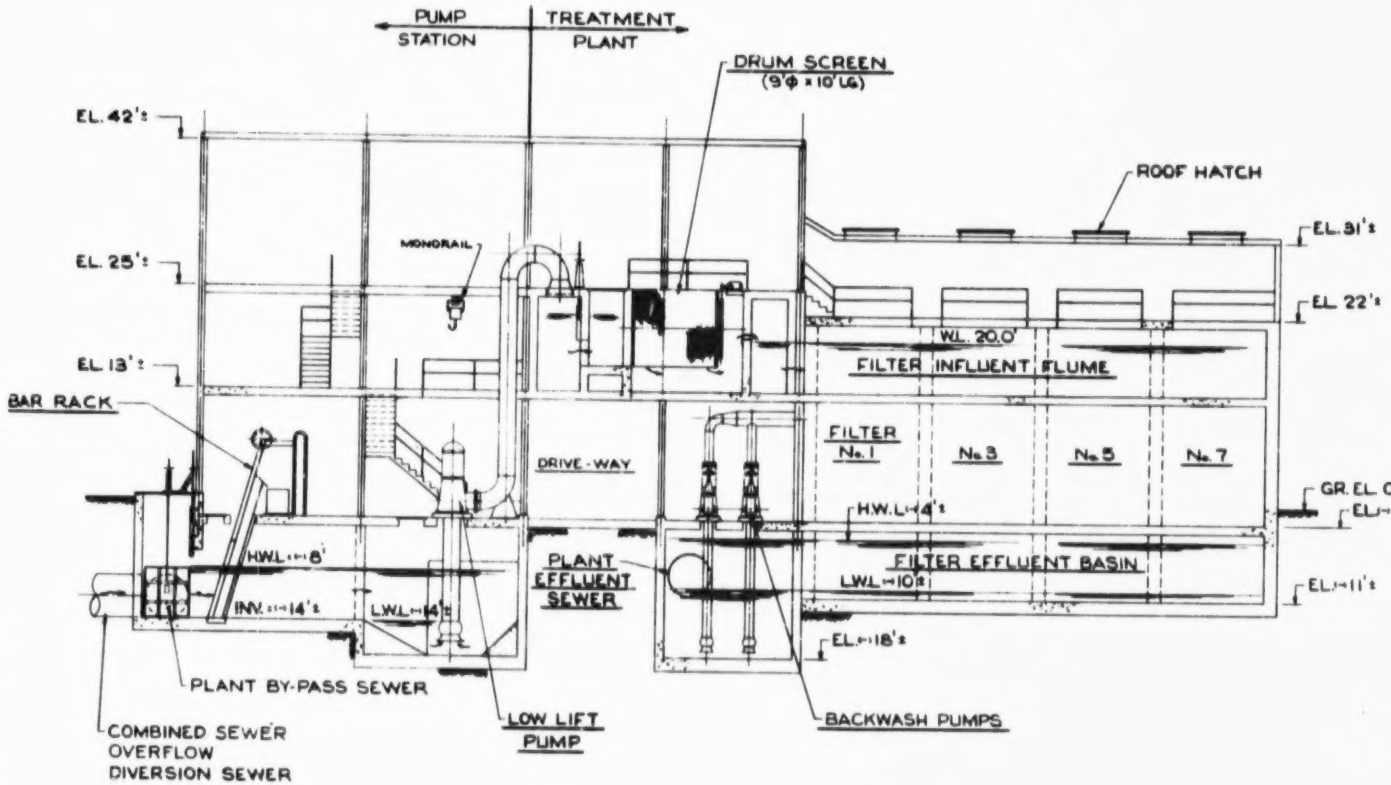


FIGURE 19

ELEVATION

HIGH RATE FILTRATION INSTALLATION — 50 MGD CAPACITY

Figure 20 shows a general arrangement for a 100 MGD high rate filtration installation. The basic filter size for this treatment system is 18 feet by 20 feet. As indicated on this drawing, the plant could be expanded to a capacity of 200 MGD, with a total of 16 filters. A longitudinal section through the 100 MGD high rate filtration facility is shown in Figure 21. Basic arrangements and area functions are similar to the two previously discussed plants (25 and 50 MGD). This particular treatment plant would be equipped with four drum screens, each 11 foot 6 inches in diameter by 7 feet long. There are eight filter units, with provision for expansion to 16, if this was desired in a future stage. As in the other filtration plant arrangements, a truck driveway is provided across the bottom floor of the plant to provide easy access for vehicles and chemical delivery.

Figure 22 shows a typical cross section of the filtration portion of the treatment plant with the filtration units arranged symetrically about the center line of the filter bay. Water is fed through the filter influent flume then into each individual filter gullet and subsequently into the filter media bed. The filtered water flows downward through the media and filter bottom and out the filter effluent pipe, dropping into the plant effluent flume. The filter arrangement as shown, is somewhat similar to a gravity filtration arrangement common to many potable water treatment plant, except that the depth of the media is much greater. The effluent flume is extended under the entire width of the filter bay to provide for sufficient backwash water storage. The treated effluent then flows by gravity to the appropriate water body.

Two access areas are provided, one along the top of the filter and one between the filter pipework, near the bottom of the filter, which offers an access corridor for servicing and maintaining the automatic valves and flow tubes that are in integral part of each filter unit. Roof hatches are provided at the top of the filter enclosure, appropriately located in the center of each filter unit. Removable backwash troughs permit media changing via an overhead crane, with access through roof hatches. All the valves integral to the filtration operation would be automated so that a full time operator would not be required.

As indicated previously, the gravity design has a number of advantages and optimal features. Perhaps two of the most important are: first, that an open type filter unit provides an access for gas release through the media bed, a possible problem due to materials of domestic or industrial origin in the combined sewer overflow; and secondly, with the gravity type arrangement, an individual filter unit can be easily isolated from the remainder of the filters, without impeding filtration operation or requireing a temporary plant shutdown for maintenance.

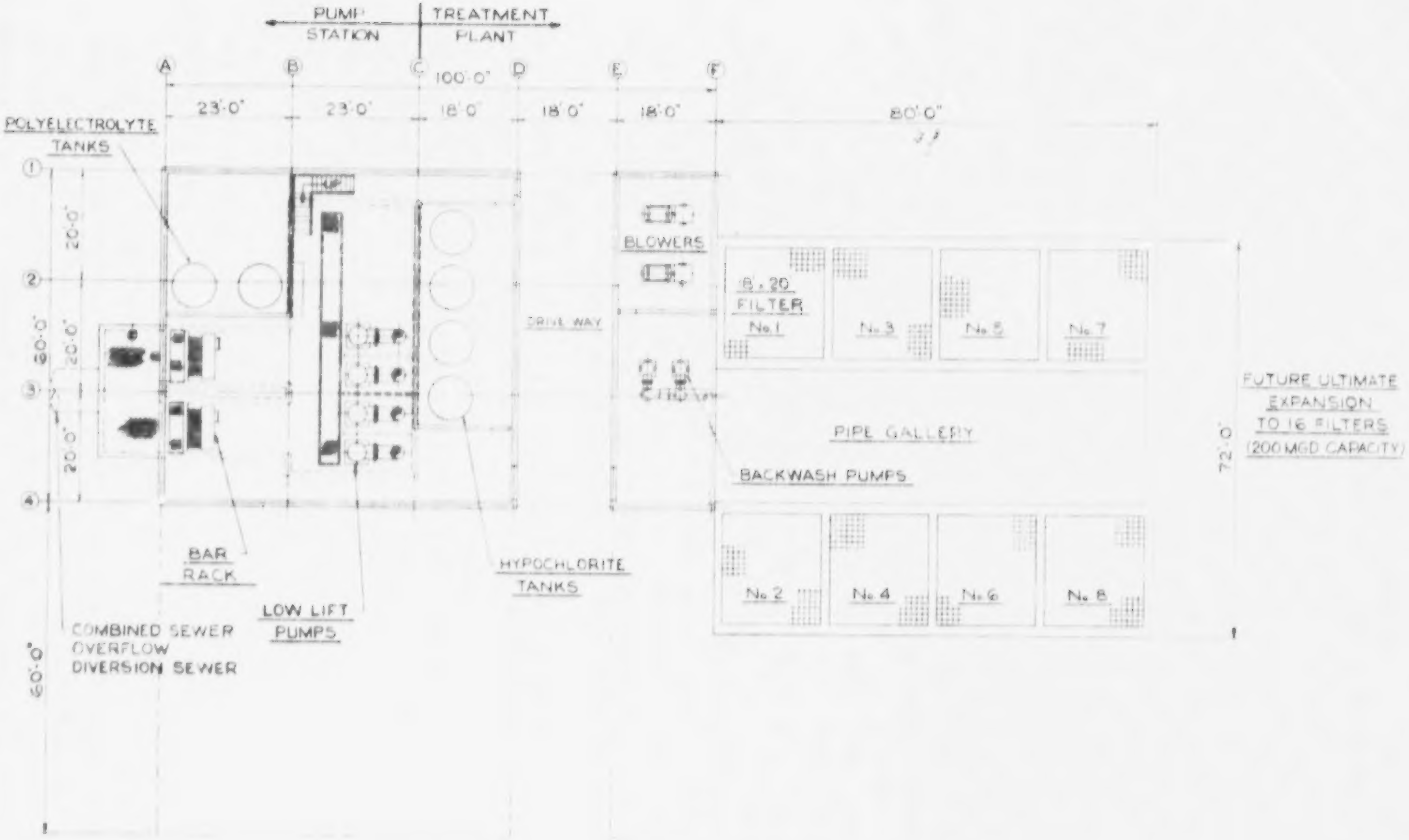


FIGURE 20

PLAN

HIGH RATE FILTRATION INSTALLATION - 100 MGD CAPACITY

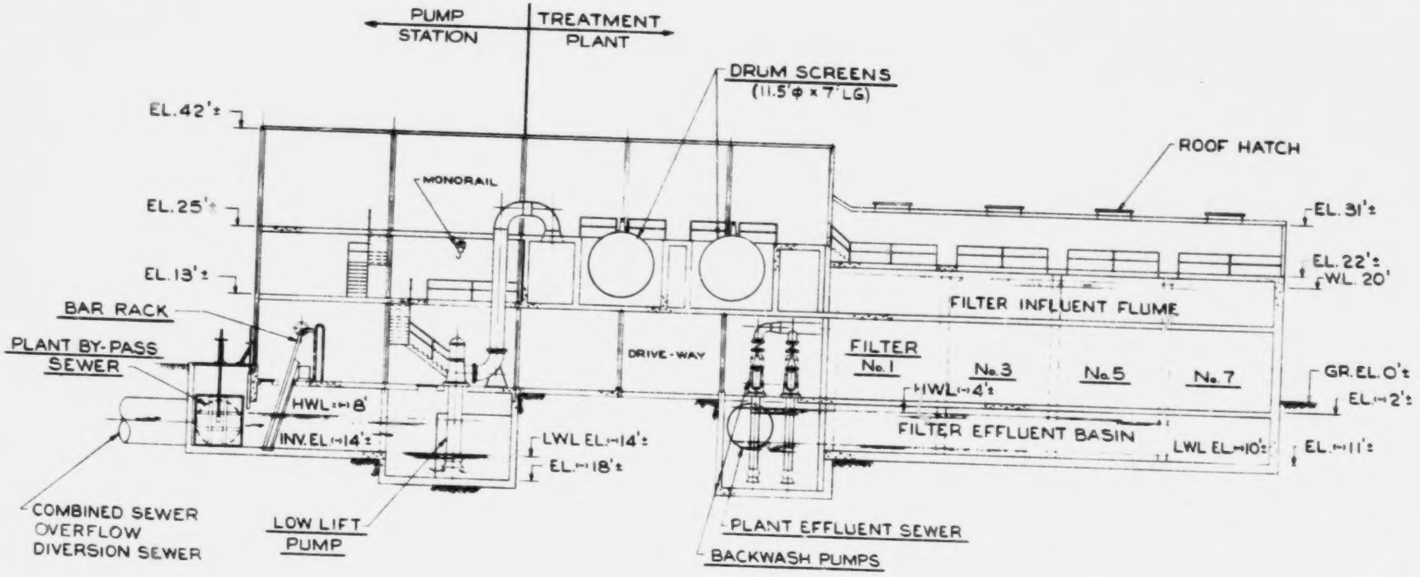


FIGURE 21

ELEVATION

HIGH RATE FILTRATION INSTALLATION — 100 MGD CAPACITY

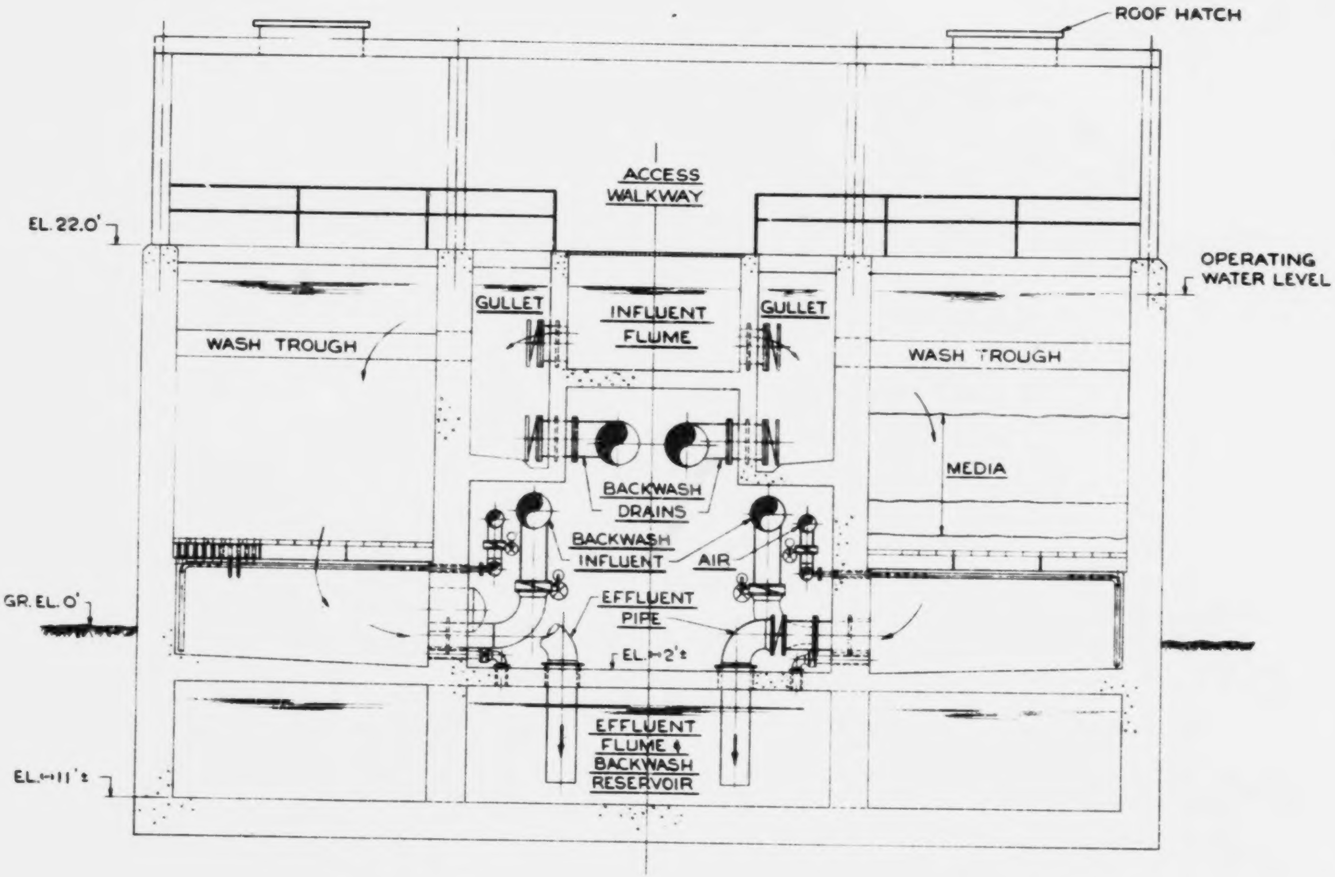


FIGURE 22

HIGH RATE FILTRATION INSTALLATION - TYPICAL FILTER SECTION

Figure 23 is a rendering of a typical high rate filtration installation. This particular plant would have a treatment capacity of 100 MGD, and is the ultimate development of the 25 MGD treatment facility. The proposed facilities can be enclosed so that the nature and functioning of the equipment inside the facility would not be readily apparent. With this proposed arrangement, plants utilizing the high rate filtration process in facilities of similar design to the one shown in Figure 23 could be easily adapted and located in varying parts of a municipality, without interfering with the architectural or aesthetic quality of the neighborhood. Perhaps the most significant advantage of high rate filtration of combined sewer overflows, in addition to its good removal of a suspended material and other contaminants, is the limited space required for a facility with such a large treatment capacity. The area requirements for high rate filtration plants treating combined sewer overflows are shown as follows:

| Plant Capacity (MGD) | Area Requirements Design @ 24 gpm/sq ft ( sq ft ) |
|---|---|
| 25 | 3,000 |
| 50 | 4,600 |
| 100 | 9,300 |
| 200 | 16,500 |

The area requirements of a high rate filtration treatment system would approximate 20 percent or less, of the spare requirements for an alternate flotation treatment system (design at 3 gpm/sq ft surface loading) (22).

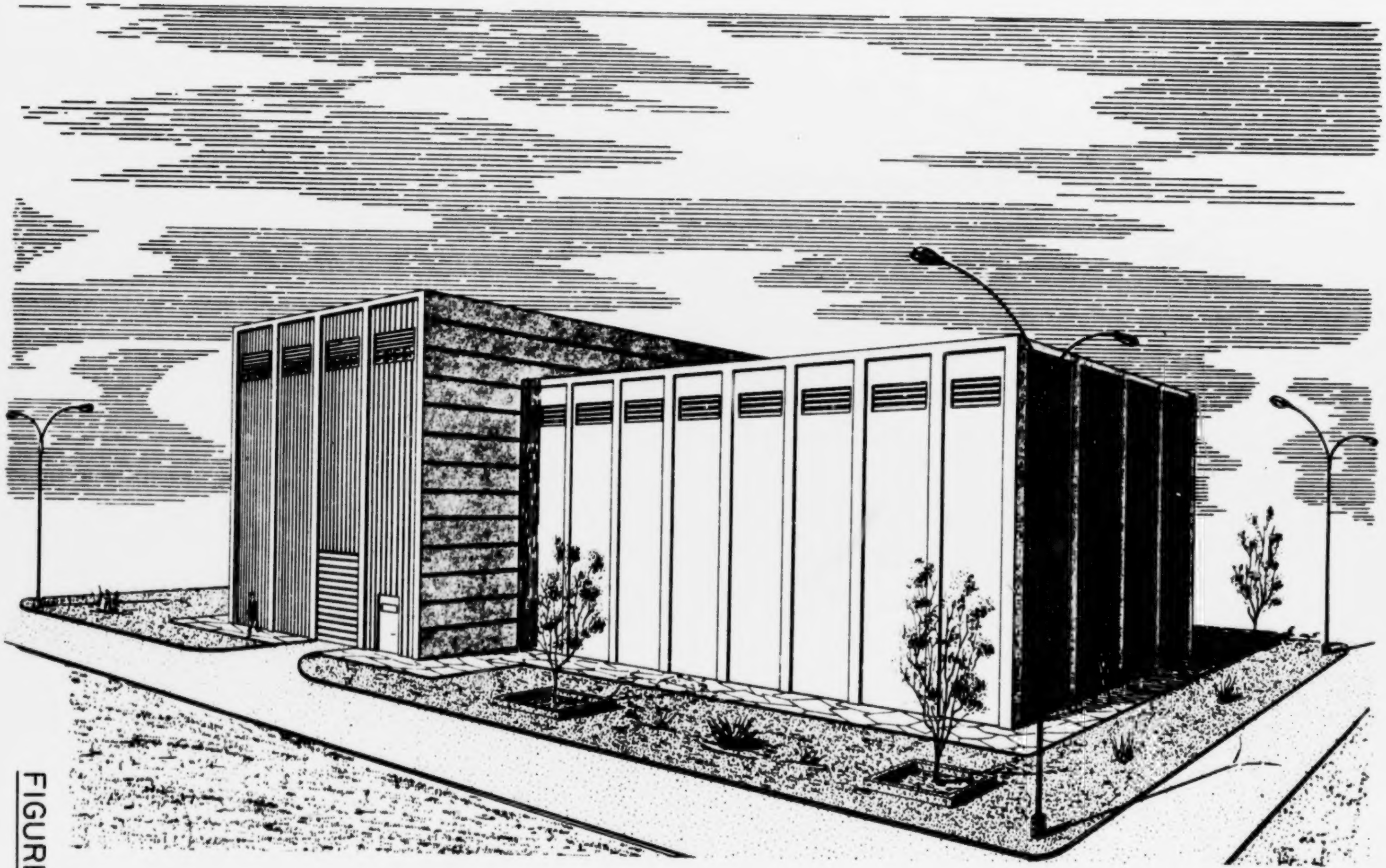
<br>

FIGURE 23

HIGH RATE FILTRATION INSTALLATION – RENDERING

# SECTION XI

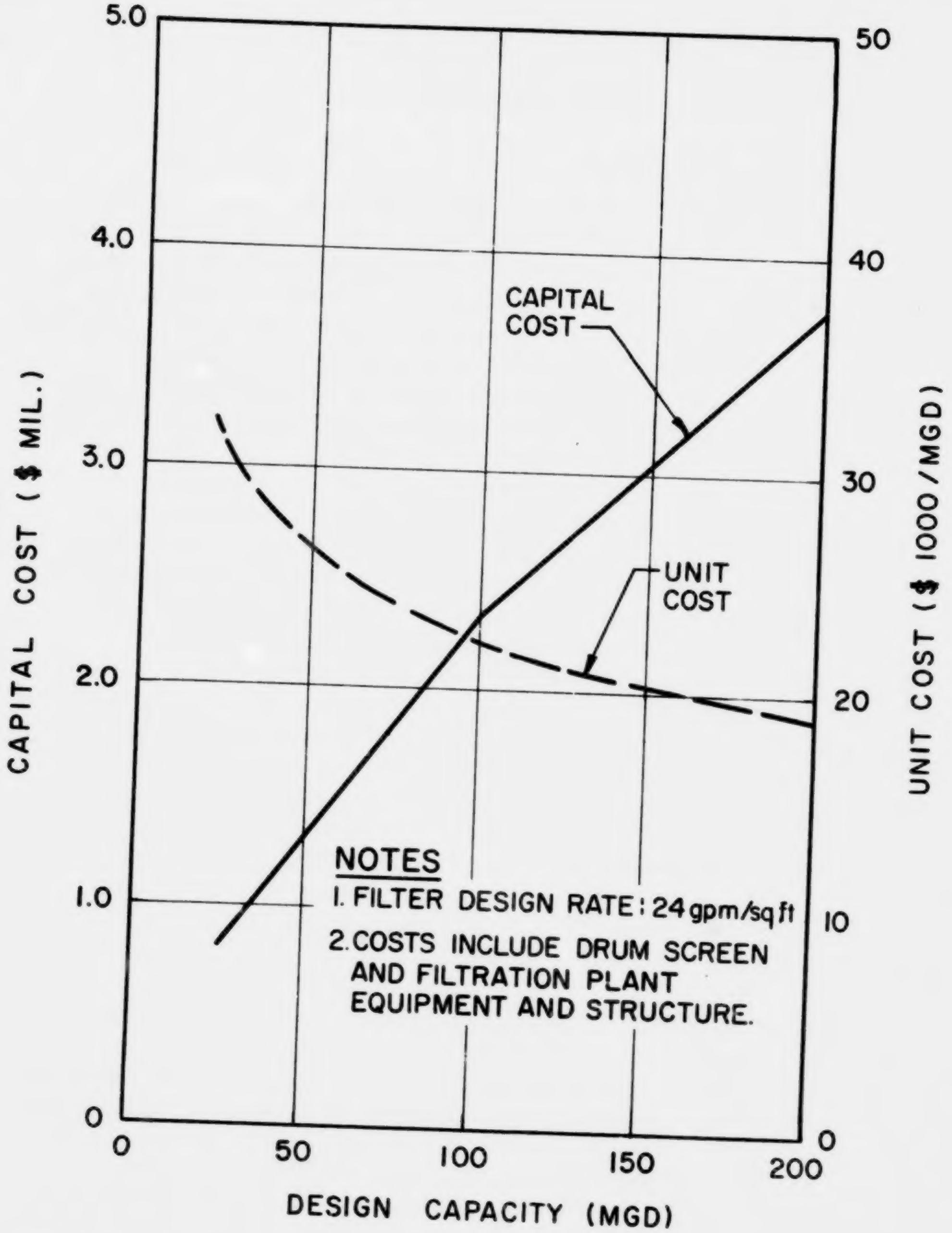
# COST ESTIMATES

## Cost of High Rate Filtration

In developing unit cost estimates for a particular wastewater treatment process, it is necessary to make a number of assumptions defining a treatment plant which would be typical for many conditions. This has been accomplished in the preceeding section. Depending on the location, cost data developed for a particular treatment plant could be either high or low. This approach provides general order of magnitude information which can be utilized to determine what systems deserve consideration as potential treatment processes to solve the problem of combined sewer overflows.

As noted in the preceeding section, general designs were developed for a treatment facility to accommodate combined sewer overflows,including the integration of a low lift pump station with the treatment essentials. In arriving at representative cost data that can be compared with other potential solutions for the treatment of combined sewer overflows, the cost of the influent pumping station has been seperated from the total cost of the facility, so that the costs will represent costs of the treatment facilities. Wastewater collection and conveyance costs, either to or from the treatment facilities, would probably be extremely variable from one installation to another and would apply to most processes considered. The treatment plant costs presented in the summary curves contained in this section can be compared with alternate processes or engineering schemes, with associated cost-benefit relationships, for the control of pollution from combined sewage storm overflows.

Cost estimates for filtration facilities for treating combined sewage storm overflows are presented for 25 to 200 MGD capacity plants. This range covers most areas of potential application. The engineering conceptual design shown in the previous section was based on a filtration facility utilizing a design rate of 24 gpm/sq ft, including polyelectrolyte addition . Total construction costs of a filtration facility for treating combined sewage storm overflows are presented in Figure 24. Capital costs data for the filtration plant includes: the cost of equipment, installation and construction costs, and a 12 percent allowance for contingencies, plus a 10 percent allowance for engineering and administration of the proposed construction. Detailed cost breakdowns, estimated for 25 to 200 MGD plant, including cost data for low lift pump station are



ESTIMATED CAPITAL COST Vs DESIGN CAPACITY

FIGURE 24

presented in Tables 23 through 26.

Estimated total construction costs (Figure 24) of a filtration plant for treating combined sewer overflows range from $830,000 for the 25 MGD capacity to $3,754,000 for 200 MGD capacity at design rate of 24 gpm/sq ft.

Figure 25 presents total annual costs for a high rate filtration plant. These costs are based on 300 hours of facility operation per year. Other criteria used in developing the annual cost are:

a. Interest at six percent for 25 years.

b. Maintenance at three percent of mechanical equipment cost and at two percent of electrical and instrumentation cost.

c. Labor at $15,000 per man year, including overhead and benefits.

d. Chemical application of polyelectrolyte to filter influent at 1.0 mg/l and application of 15 mg/l chlorine to filter backwash.

e. Electricity at $.03 per Kw - Hr.

Estimated annual cost data ranges from $97,270 per year for a 25 MGD capacity plant to $388,210 per year for a 200 MGD capacity plant. Annual treatment costs utilizing the high rate filtration process are due primarily to interest and amortization charges, and are less affected by the volume of combined sewer overflow to be treated annually. Estimated detailed cost breakdowns for annual operating and maintenance are presented in Tables 27 through 30.

The most significant costs associated with the high rate filtration facility are reflected in interest and amortization payments, as the operating costs are minimal due to the automated operation of the facility and the relatively small number of hours of operation per year. As is evidenced from the previous section, the filtration plant design and the associated housing of process units, is one that would be suitable for a cold climate. In warmer areas, and in location where local engineering practices permit a more compressed equipment management, the enclosure could be taken off the filtration facility and much of the related process equipment. It may also be possible to

## Table 23

## SUMMARY OF ESTIMATED PROJECT COSTS*

## FOR 25 MGD TREATMENT PLANT

| | PEAK FILTRATION RATE DESIGNED | |
|---|---|---|
| | 24 gpm/sq ft | 16 gpm/sq ft |
| I. PUMPING STATION | | |
| Excavation and Backfill | $ 3,800 | $ 3,800 |
| Reinforced Concrete | 38,500 | 38,500 |
| Building | 50,000 | 50,000 |
| Bar Screen | 20,000 | 20,000 |
| Pump | 80,000 | 80,000 |
| Piping | 5,000 | 5,000 |
| Heating and Ventilating | 10,000 | 10,000 |
| Electrical | 40,000 | 40,000 |
| Plumbing, Lighting, Interior &etc. | 20,000 | 20,000 |
| Sub-total | $ 267,300 | $ 267,300 |
| Construction Contingency | 32,000 | 32,000 |
| Sub-total Construction Cost | $ 299,300 | $ 299,300 |
| Engineering and Administration | 30,000 | 30,000 |
| Project Sub-total, Conveyance Portion | $ 329,300 | $ 329,300 |

Table 23 (continued)

| | | |
|---|---|---|
| II. TREATMENT PLANT | | |
| Excavation and Backfill | $ 8,000 | $ 11,000 |
| Reinforced Concrete | 142,000 | 202,000 |
| Building | 81,000 | 92,000 |
| Drum Screen | 70,000 | 70,000 |
| Filter Media & Filter Bottom | 20,000 | 30,000 |
| Filter Backwash Pump | 20,000 | 20,000 |
| Air Blower | 20,000 | 20,000 |
| Piping | 110,000 | 160,000 |
| Polyelectrolyte Feed | 20,000 | 20,000 |
| Chlorination Equipment | 30,000 | 30,000 |
| Heating and Ventilating | 15,000 | 15,000 |
| Electrical | 50,000 | 50,000 |
| Instrumentation | 52,000 | 70,000 |
| Plumbing, Lighting, Interior & etc. | 40,000 | 45,000 |
| Sub-total | $ 678,000 | $ 835,000 |
| Construction Contingency (12%) | 81,000 | 100,200 |
| Sub-total Construction Costs | $ 759,000 | $ 935,200 |
| Engineering & Administration (10%) | 71,000 | 93,500 |
| Project Sub-total Treatment Portion | $ 830,000 | $1,028,700 |
| III TOTAL PROJECT COSTS | $1,159,300 | $1,338,000 |

* Engineering News Record Construction Cost Index = 1470

## Table 24

## SUMMARY OF ESTIMATED PROJECT COSTS*

## FOR 50 MGD TREATMENT PLANT

| | PEAK FILTRATION RATE DESIGNED | |
|---|---|---|
| | 24 gpm/sq ft | 16 gpm/sq ft |
| I. PUMPING STATION | | |
| Excavation and Backfill | $ 3,800 | $ 3,800 |
| Reinforced Concrete | 38,500 | 38,500 |
| Building | 50,000 | 50,000 |
| Bar Screen | 20,000 | 20,000 |
| Pump | 140,000 | 140,000 |
| Piping | 10,000 | 10,000 |
| Heating and Ventilating | 12,000 | 12,000 |
| Electrical | 60,000 | 60,000 |
| Plumbing, Lighting, Interior & etc. | 25,000 | 25,000 |
| Sub-total | $ 359,300 | $ 359,300 |
| Construction Contingency | 43,100 | 43,100 |
| Sub-total Construction Cost | $ 402,400 | $ 402,400 |
| Engineering and Administration | 40,200 | 40,200 |
| Project Sub-total, Conveyance Portion | $ 442,600 | $ 442,600 |

Table 24 (continued)

## II. TREATMENT PLANT

| | | |
|---|---|---|
| Excavation and Backfill | $ 11,000 | $ 14,000 |
| Reinforced Concrete | 252,000 | 367,000 |
| Building | 102,000 | 122,000 |
| Drum Screen | 140,000 | 140,000 |
| Filter Media and Filter Bottom | 40,000 | 60,000 |
| Filter Backwash Pump | 20,000 | 20,000 |
| Air Blower | 20,000 | 20,000 |
| Piping | 212,000 | 314,000 |
| Polyelectrolyte Feed | 20,000 | 20,000 |
| Chlorination Equipment | 30,000 | 30,000 |
| Heating and Ventilating | 18,000 | 18,000 |
| Electrical | 60,000 | 60,000 |
| Instrumentation | 90,000 | 120,000 |
| Plumbing, Lighting, Interior & etc. | 50,000 | 55,000 |
| Sub-total | $1,065,000 | $1,360,000 |
| Construction Contingency (12%) | 128,000 | 163,200 |
| Sub-total Construction Costs | $1,193,000 | $1,523,200 |
| Engineering & Administration (10%) | 119,300 | 152,300 |
| Project Sub-total, Treatment Portion | $1,312,300 | $1,675,500 |
| III. TOTAL PROJECT COSTS | $1,754,900 | $2,118,100 |

* Engineering News Record Construction Cost Index = 1470

Table 25

## SUMMARY OF ESTIMATED PROJECT COSTS*

## FOR 100 MGD TREATMENT PLANT

| | PEAK FILTRATION RATE DESIGNED | |
|---|---|---|
| | 24 gpm/sq ft | 16 gpm/sq ft |
| **I. PUMP STATION** | | |
| Excavation and Backfill | $ 5,300 | $ 5,300 |
| Reinforced Concrete | 75,000 | 75,000 |
| Building | 112,000 | 112,000 |
| Bar Screen | 40,000 | 40,000 |
| Pump | 255,000 | 255,000 |
| Piping | 15,000 | 15,000 |
| Heating and Ventilating | 20,000 | 20,000 |
| Electrical | 150,000 | 150,000 |
| Plumbing, Lighting, Interior & etc. | 30,000 | 30,000 |
| Sub-total | $ 702,300 | $ 702,300 |
| Construction Contingency | 84,300 | 84,300 |
| Sub-total Construction Cost | $ 786,600 | $ 786,600 |
| Engineering & Administration | 78,700 | 78,700 |
| Project Sub-total, Conveyance Portion | $ 865,300 | $ 865,300 |

Table 25 (continued)

| | | |
|---|---|---|
| II. TREATMENT PLANT | (continued) | |
| Excavation and Backfill | $ 20,000 | $ 20,600 |
| Reinforced Concrete | 470,000 | 715,000 |
| Building | 210,000 | 250,000 |
| Drum Screen | 280,000 | 280,000 |
| Filter Media and Filter Bottom | 80,000 | 120,000 |
| Filter Backwash Pump | 36,000 | 36,000 |
| Air Blower | 36,000 | 36,000 |
| Piping | 416,000 | 620,000 |
| Polyelectrolyte Feed | 30,000 | 30,000 |
| Chlorination Equipment | 45,000 | 45,000 |
| Heating and Ventilating | 30,000 | 30,000 |
| Electrical | 90,000 | 90,000 |
| Instrumentation | 95,000 | 130,000 |
| Plumbing, Lighting, Interior & etc. | 70,000 | 80,000 |
| Sub-total | $1,908,000 | $2,488,000 |
| Construction Contingency (12%) | 229,000 | 298,600 |
| Sub-total Construction Costs | $2,137,000 | $2,786,600 |
| Engineering & Administration (10%) | 214,000 | 278,700 |
| Project Sub-total, Treatment Portion | $2,351,000 | $3,065,300 |
| III. TOTAL PROJECT COSTS | $3,216,300 | $3,930,600 |

* Engineering News Record Construction Cost Index = 1470

Table 26

SUMMARY OF ESTIMATED PROJECT COSTS*

FOR 200 MGD TREATMENT PLANT

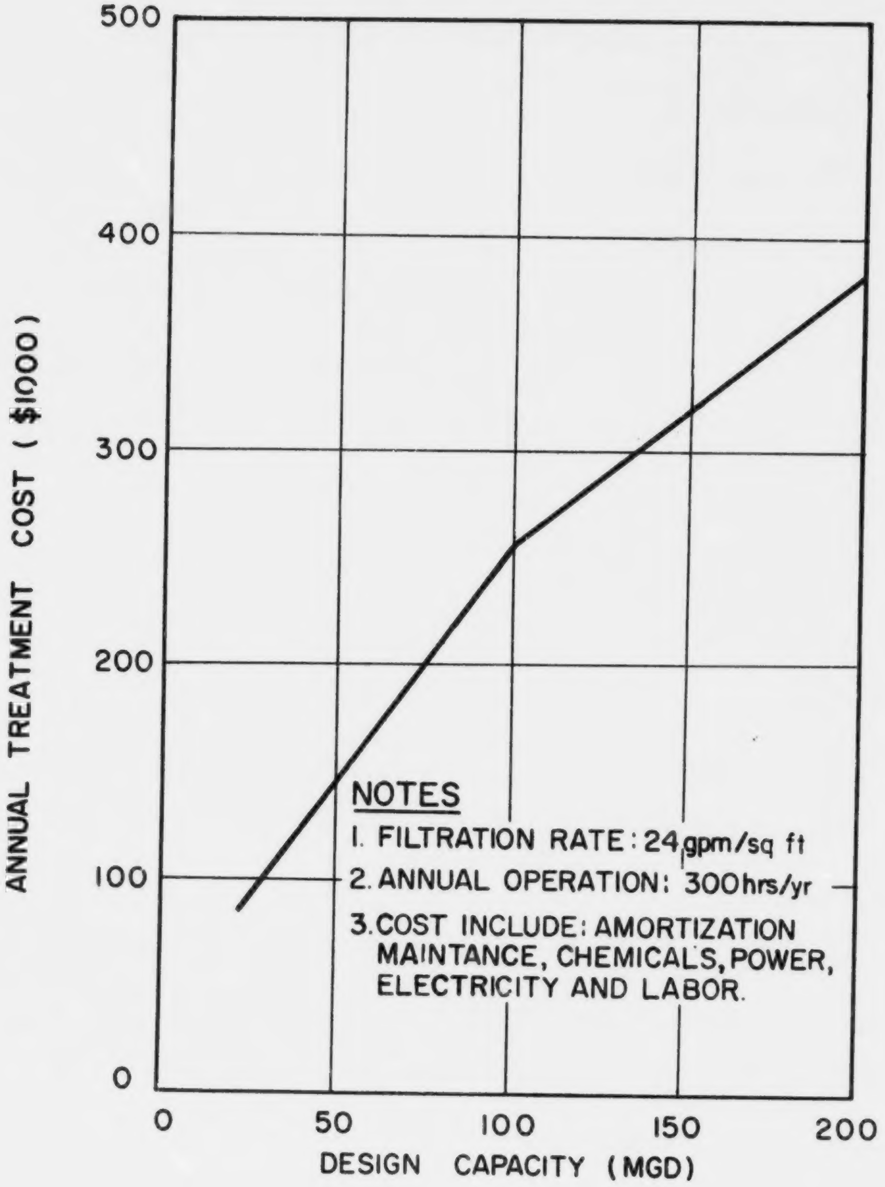
| | PEAK FILTRATION RATE DESIGNED | |
|---|---|---|
| | 24 gpm/sq ft | 16 gpm/sq ft |
| I. PUMPING STATION | | |
| Excavation and Backfill | $ 10,700 | $ 10,700 |
| Reinforced Concrete | 150,000 | 150,000 |
| Building | 224,000 | 224,000 |
| Bar Screen | 80,000 | 80,000 |
| Pump | 480,000 | 480,000 |
| Piping | 25,000 | 25,000 |
| Heating and Ventilating | 30,000 | 30,000 |
| Electrical | 330,000 | 330,000 |
| Plumbing, Lighting, Interior & etc. | 60,000 | 60,000 |
| Sub-total | $1,389,700 | $1,389,700 |
| Construction Contingency | 166,800 | 166,800 |
| Sub-total Construction Cost | $1,556,500 | $1,556,500 |
| Engineering & Administration | 155,600 | 155,600 |
| Project Sub-total, Conveyance Portion | $1,712,100 | $1,712,100 |

Table 26 (continued)

## II. TREATMENT PLANT

| | | |
|---|---|---|
| Excavation and Backfill | $ 40,000 | $ 52,000 |
| Reinforced Concrete | 800,000 | 1,120,000 |
| Building | 400,000 | 470,000 |
| Drum Screen | 480,000 | 480,000 |
| Filter Media and Filter Bottom | 160,000 | 240,000 |
| Filter Backwash Pump | 36,000 | 36,000 |
| Air Blower | 36,000 | 36,000 |
| Piping | 548,000 | 815,000 |
| Polyelectrolyte Feed | 50,000 | 50,000 |
| Chlorination Equipment | 65,000 | 65,000 |
| Heating and Ventilating | 42,000 | 42,000 |
| Electrical | 130,000 | 130,000 |
| Instrumentation | 170,000 | 240,000 |
| Plumbing, Lighting, Interior & etc. | 90,000 | 100,000 |
| Sub-Total | $3,047,000 | $3,876,000 |
| Construction Contingency (12%) | 365,600 | 465,100 |
| Sub-total Construction Costs | $3,412,600 | $4,341,100 |
| Engineering & Administration (10%) | 341,000 | 434,100 |
| Project sub-total, Treatment Portion | $3,753,600 | $4,775,100 |
| III. TOTAL PROJECT COSTS | $5,465,700 | $6,487,200 |

* Engineering News Record Construction Cost Index = 1470



ESTIMATED ANNUAL TREATMENT COST Vs DESIGN CAPACITY

FIGURE 25

## Table 2.7

## SUMMARY OF ESTIMATED ANNUAL COSTS*

## FOR 25 MGD TREATMENT PLANT

| | PEAK FILTRATION RATE DESIGNED | |
|---|---|---|
| | 24 gpm/sq ft | 16 gpm/sq ft |
| I. AMORTIZATION | | |
| 6 percent Interest Rate for 25 years | $ 65,000 | $ 80,000 |
| II. OPERATING COSTS | | |
| Labor (Includes Overhead & Benefits) | $ 20,000 | $ 20,000 |
| Maintenance | | |
| Mechanical Equipment (3% of Equipment Cost) | $ 5,250 | $ 5,250 |
| Electrical & Instrumentation (2% of Equipment Cost) | $ 2,040 | $ 2,400 |
| Piping (1% of Piping Cost) | $ 1,100 | $ 1,600 |
| Utilities | | |
| Electrical($.03/KWH) | $ 600 | $ 600 |
| Chemicals | | |
| Chlorine**(15 mg/l) | $ 100 | $ 100 |
| Polyelectrolyte(0.5 mg/l) | 3,180 | 3,180 |
| Operating Costs Sub-total | $ 32,270 | $ 33,130 |
| Total Annual Costs | $ 97,270 | $ 113,130 |

* For Treatment Portion Annual Cost
** For Filter Backwash

## Table 28

## SUMMARY OF ESTIMATED ANNUAL COSTS*

## FOR 50 MGD TREATMENT PLANT

| | PEAK FILTRATION RATE DESIGNED | |
|---|---|---|
| | 24 gpm/sq ft | 16 gpm/sq ft |
| I. AMORTIZATION | | |
| 6 percent Interest Rate for 25 years | $ 102,700 | $ 131,000 |
| II. OPERATING COSTS | | |
| Labor (Includes Overhead & Benefits) | $ 20,000 | $ 20,000 |
| Maintenance | | |
| Mechanical Equipment (3% of Equipment Cost) | $ 7,430 | $ 7,440 |
| Electrical & Instrumentation (2% of Equipment Cost) | $ 3,000 | $ 3,600 |
| Piping(1% of Piping Cost) | $ 2,120 | $ 3,140 |
| Utilities | | |
| Electrical($.02/KWH) | $ 1,200 | $ 1,200 |
| Chemicals | | |
| Chlorine**(15 mg/l) | $ 200 | $ 200 |
| Polyelectrolyte(0.5mg/l) | 6,350 | 6,350 |
| Operating Costs Sub-total | $ 40,300 | $ 41,930 |
| Total Annual Costs | $ 143,000 | $ 172,930 |

* For Treatment Portion Annual Cost.
** For Filter Backwash.

## Table 29

## SUMMARY OF ESTIMATED ANNUAL COSTS* FOR 100 MGD TREATMENT PLANT

| | PEAK FILTRATION RATE DESIGNED | |
|---|---|---|
| | 24 gpm/sq ft | 16 gpm/sq ft |
| I. AMORTIZATION | | |
| 6 percent Interest Rate for 25 years | $ 184,000 | $ 239,000 |
| II. OPERATING COSTS | | |
| Labor (Includes Overhead & Benefits) | $ 35,000 | $ 35,000 |
| Maintenance | | |
| Mechanical Equipment (3% of Equipment Cost) | $ 13,710 | $ 13,710 |
| Electrical & Instrumentation (2% of Equipment Cost) | $ 3,700 | $ 4,400 |
| Piping (1% of Piping Cost) | $ 4,160 | $ 6,200 |
| Utilities | | |
| Electrical ($.02/KWH) | $ 2,400 | $ 2,400 |
| Chemicals | | |
| Chlorine** (15mg/l) | $ 400 | $ 400 |
| Polyelectrolyte (0.5mg/l) | 12,720 | 12,720 |
| Operating Costs Sub-total | $ 72,100 | $ 74,830 |
| Total Annual Costs | $ 256,100 | $ 313,830 |

* For Treatment Portion Annual Cost
** For Filter Backwash

## Table 30

## SUMMARY OF ESTIMATED ANNUAL COSTS*

## FOR 200 MGD TREATMENT PLANT

| | PEAK FILTRATION RATE DESIGNED | |
|---|---|---|
| | 24 gpm/sq ft | 16 gpm/sq ft |
| I. AMORTIZATION | | |
| 6 percent Interest Rate for 25 years | $ 293,500 | $ 373,400 |
| II. OPERATING COSTS | | |
| Labor (Includes Overhead & Benefits) | $ 50,000 | $ 50,000 |
| Maintenance | | |
| Mechanical Equipment (3% of Equipment Costs) | $ 21,270 | $ 21,270 |
| Electrical & Instrumentation (2% of Equipment Cost) | $ 6,000 | $ 7,400 |
| Piping (1% of Piping Cost) | 5,480 | 8,150 |
| Utilities | | |
| Electrical ($.02/KWH) | $ 4,800 | $ 4,800 |
| Chemicals | | |
| Chlorine** (15 mg/l) | $ 800 | $ 800 |
| Polyelectrolyte (0.5mg/l) | 6,360 | 6,360 |
| Operating Costs Sub-total | $ 94,710 | $ 98,780 |
| Total Annual Costs | $ 388,210 | $ 472,180 |

* For treatment Portion Annual Cost
** For Filter Backwash.

compress the site requirements, especially in the building, resulting in a reduction of both capital and operating costs in order of 10 to 20 percent.

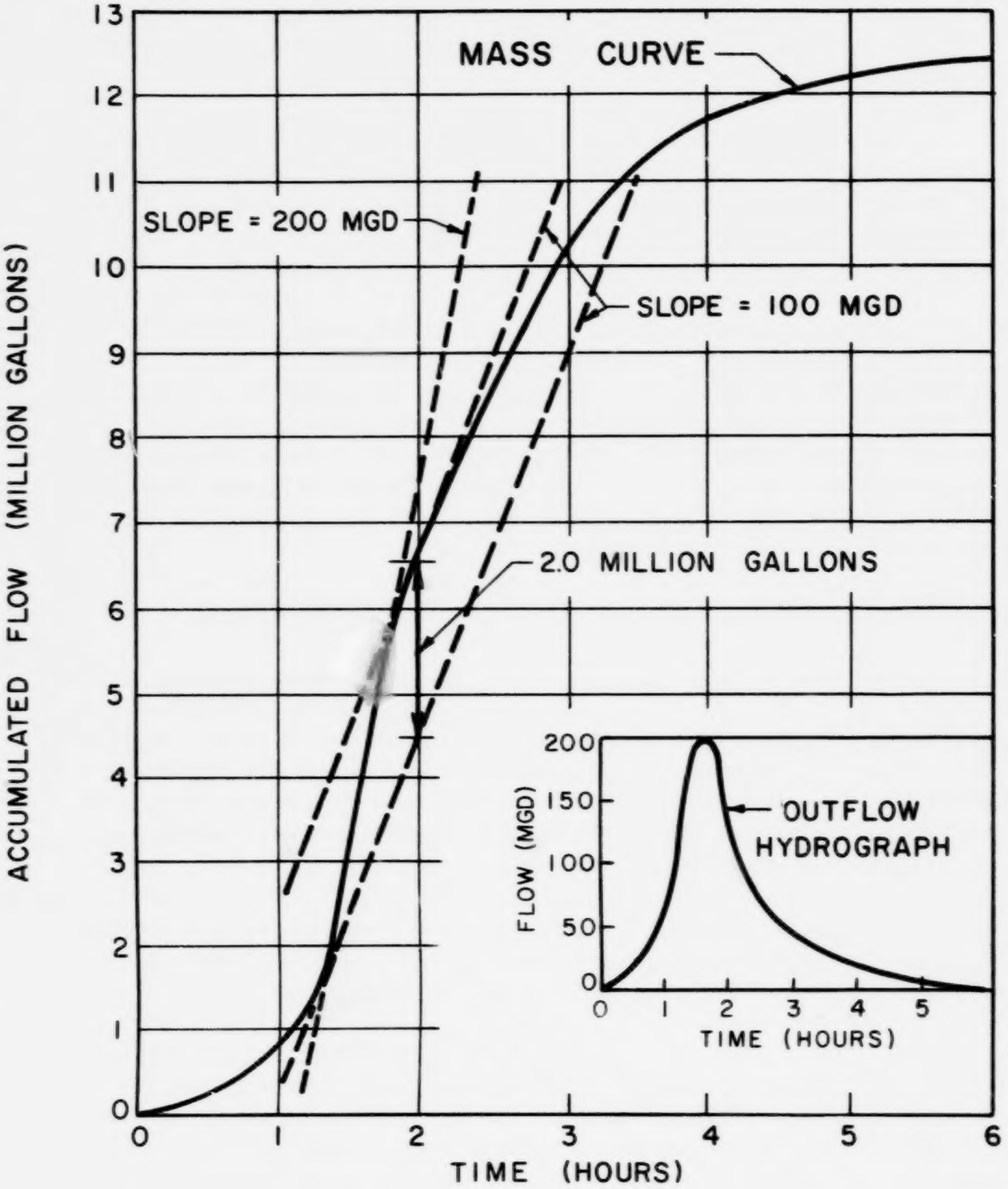
The previous paragraphs have delineated capital and operating costs associated with high rate filtration installations in the treatment of combined sewer overflows. These costs do not include disposal of waste screenings and filter backwash since the proposed system would discharge these to the municipal sewage treatment plant.

Solids handling and disposal costs for municipal sewage treatment facilities cover a great range, varying from $5 to $55 per ton of dry solids (24). Assuming an average of 200 mg/l of solids removed, and a combined sewer overflow treatment plant operation of 300 hours per year, solids processing and disposal costs incurred by the municipal sewage treatment plant could range from 3 to 35 percent of the total annual charges for the combined sewer overflow treatment facility.

## Selection of High Rate Filtration Plant Capacity with Storage

The selection of the appropriate capacity for a high rate filtration plant to treat combined sewer overflows should be based on results of a cost effectiveness analysis. To achieve the highest cost effectiveness system, an optimum storage capacity should be included in defining treatment plant size. The temporary storage of combined sewer overflows moderates the peak loadings contributed by intense storms and avoids excessive treatment plant capacity. However, the size of storage area depends on local conditions such as sewer capacity (in-stream storage) and land availability (off-stream storage). This approach allows the selection of the highest cost effectiveness system for each particular situation.

A typical example of the estimated capital costs for various treatment plants and storage capacities is presented in Table 31. This example utilizes an off-stream storage tank and is based on a synthetic outflow hydrograph for combined sewer overflow without consideration of storage in a main sewer. The overflow hydrograph is based on a peak flow rate of 200 MGD with a time of concentration of approximately 90 minutes and a total duration of six hours as shown in Figure 26.



USE OF A MASS CURVE TO DETERMINE THE STORAGE CAPACITY REQUIRED FOR A TYPICAL STORM OVERFLOW

FIGURE 26

Table 31

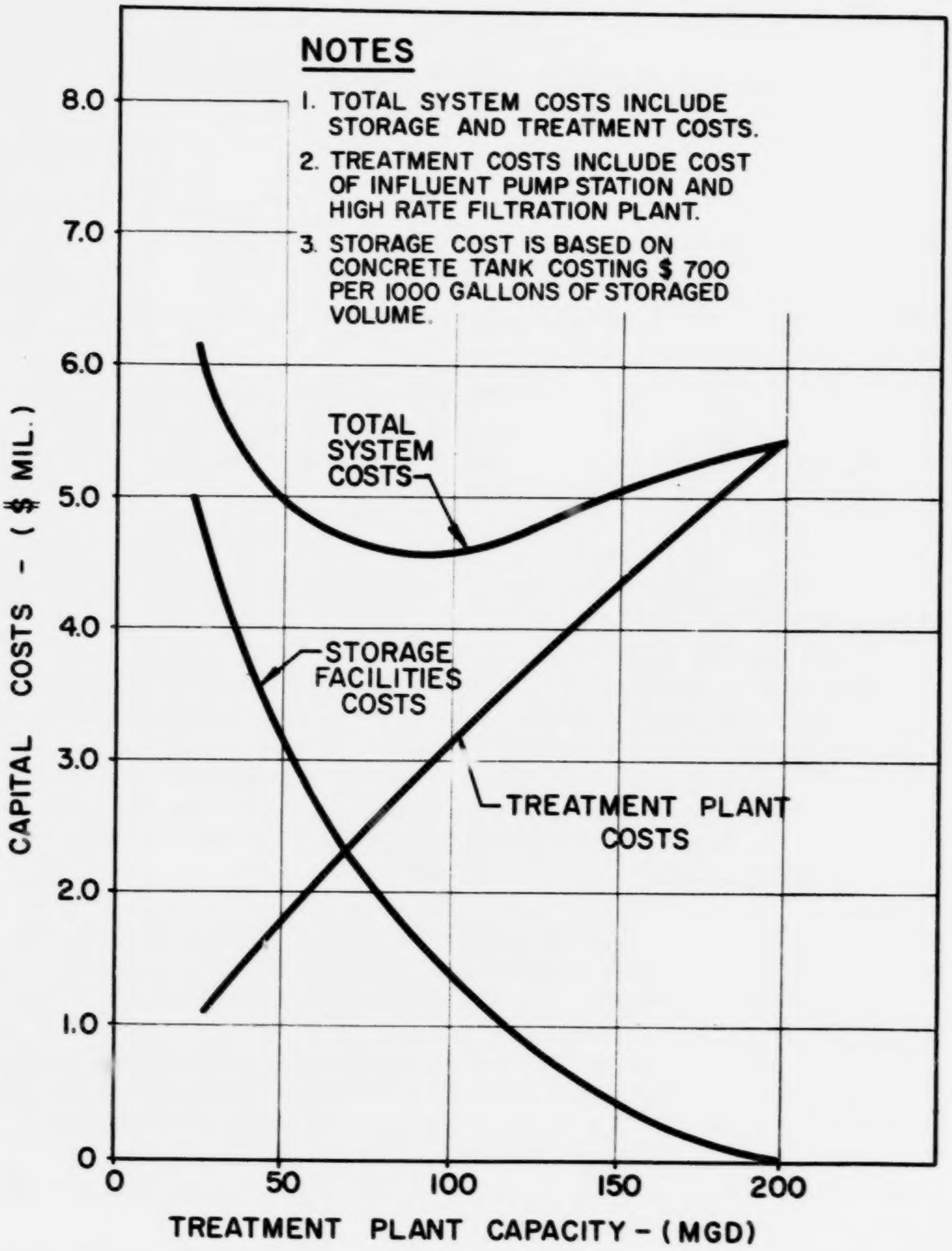
## ESTIMATED CAPITAL COSTS FOR VARIOUS TREATMENT PLANT AND STORAGE CAPACITIES

| Treatment Plant (MGD) | Storage Tank (MG) | Treatment Plant Total Project Cost ($) | Storage Tank Cost ($) | Total System Cost ($) |
|---|---|---|---|---|
| 200 | 0 | 5,465,700 | 0 | 5,465,700 |
| 150 | 0.50 | 4,700,000 | 350,000 | 5,050,000 |
| 100 | 2.00 | 3,216,300 | 1,400,000 | 4,616,300 |
| 50 | 4.50 | 1,754,900 | 3,140,000 | 4,894,900 |
| 25 | 7.15 | 1,159,300 | 5,000,000 | 6,159,300 |

Figure 26 is a mass curve for a 6-hour period based on the outflow hydrograph as shown in the lower right corner of the figure. The slope of the mass curve at any time is a measure of the combined sewer overflow rate at that time. Plant influent curves representing a uniform rate of flow are straight lines having a slope equal to the treatment plant capacity. The vertical distance between successive tangents represents the overflow volume beyond plant capacity and indicates the required storage. This approach is based on constant draft while the storage tank is filling during the overflow event, and it should be utilized in conceptual design.

As shown in Table 31, and Figure 26 the storage tank is not needed for the treatment plant capacity having the same peak rate as the combined sewer overflow. By increasing the storage tank capacity, the capacity of the treatment plant can be reduced. The treatment plant total project cost includes the plant influent pumping station and the high rate filtration treatment plant as shown in Tables 23 through 26. The storage tank cost is estimated at about $700 per 1000 gallons. Storage tank costs include excavation, concrete, 10 percent for engineering and 12 percent of construction cost for contingency, but the cost of land is not included.

Figure 27 shows the estimated costs of storage, treatment and of the total system. The optimum point for system design consideration is the sag point on the total system cost curve. By considering the reduction of pollutional loading, the highest cost effectiveness for the 200 MGD peak combined sewer overflow rate is the 100 MGD high rate filtration plant in conjunction with a 2 million gallon off-stream storage tank.



ESTIMATED CAPITAL COSTS OF STORAGE AND TREATMENT FOR 200 MGD OVERFLOW

**FIGURE 27**

# SECTION XII

# PROCESS POTENTIAL AND FUTURE RESEARCH AREAS

## Treatment of Combined Sewer Overflows

The screening-filtration system delineated in the previous section, with the addition of appropriate polyelectrolyte, produces suspended solids removals in the order of 95% or better, which is a highly efficient system. Much of the the test work under the 1971 field program was directed at enhancing process performance in regard to phosphate removal, by the addition of phosphate removing coagulants (alum, etc.) The test results from this mode of filtration operation indicated that phosphate removal efficiency was less than desired, in the order of 60% removal at 8-16 gpm/sq ft, due to the inability of the system to produce, with consistency, a low suspended solids effluent. Under certain test runs, using identical coagulant and polyelectrolyte dosages from previously successful test runs, poor efficiencies were reported both in regard to phosphates and suspended solids. Visual observations of the filter media during a test run (alum plus polyelectrolyte) revealed that the filter media became saturated with solids (visually) a few hours after the test run had commenced. A possible reason for the high suspended solids in the effluent from a filter under this mode of test operation is due to the nature of the floc. The floc formed (alum plus a few hundred mg/l of influent suspended solids) seems very fluffy,, voluminous, and difficult to retain within the filter media. This indicates that excess alum may have been converted to aluminum hydroxide.

Based on work on secondary effluent filtration (25) that is, filtering the effluent from an activated sludge plant, if the influent solids to the filter could be reduced to a level in order of 50 mg/l or less, the suspended solids removal might improve substantially, and concurrently, the phosphate removal. To accomplish this may require the use of a much finer screen mesh ahead of the filter than was used throughout the testing program.

Additional pilot plant testing should be conducted to develop a more complete system, utilizing the same unit process. By using a finer screening mesh and a finer filter media, with a more comprehensive study of in-line mixing and coagulation, a more efficient and economical system could be developed.

To achieve a higher degree of treatment for removing dissolved BOD and phosphate as well as suspended solids in combined sewer overflows, a pilot plant consisting of microscreening (23 micron openings) followed by filtration with finer media should be evaluated. Suspended solids would be removed mainly by microscreening. By introducing the proper dosage of powdered activated carbon and coagulant ahead of the filtration unit, the dissolved and colloidal contaminants could be removed by carbon adsorption and coagulation, and eventually intercepted by the filter media. Probably the cost/benefit ratio would justify optimizing this system, since basic unit processes remain the same with only a moderate increase in screen sizing. Due to the intermittent operation of a full size treatment plant (about 300 hours per year in Cleveland). The additional annual costs of activated carbon could be justified by cost-benefit considerations.

A slotted screening element furnished by UOP Johnson Division was strong, rugged and maintenance free. Further study of the slotted screening elements should be considered. Redesign of the components, such as the variation of slot opening, the shape of surface wire and support rod, and the location of the support rod may be found appropriate for increasing allowable hydraulic loadings.

The Biospheric's in-line suspended solids monitor should be further investigated in a pilot study. The calibration procedure should be more carefully set up to obtain a consistent and reproducible correlation. This unit then could be considered as a sensing device to enhance automation of the filtration process by providing positive control of effluent suspended solids concentration.

Tests on microscreening (16) indicate that fine screening can produce a low suspended solids effluent, below 50 mg/l. Thus, for a high efficiency system, suspended solids would be removed mainly by microscreening, and phosphates, BOD and other contaminants in dissolved or colloidal form may be trimmed in filter by using coagulant and powdered activated carbon addition. Microscreening followed by deep bed, high rate filtration seems a possible alternative system to produce a very high quality effluent. This system should be further studies because in areas such as the Great Lakes and others where stringent control and regulation of phosphate inputs to a water body are, or will be, required, a system such as the one just described may be of applicability.

Another possibility for improving system consistency and performance, when adding phosphate reducing coagulants, might be to undertake more test work with additional polyelectrolytes and coagulant aids, etc., to see if a coagulant combination can be developed which will permit a consistently high degree of suspended solids and phosphate removal. However current indications are that the finer screen is the best way to increase process performance.

## Treatment of Secondary Effluent from an Activated Sludge Process

Test data in Appendix D shows that secondary effluent levels from an activated sludge process can be limited to approximately 5 mg/l suspended solids at filtration rates of up to 30 gpm/sq ft. The basic concept of deep bed high rate filtration for secondary effluent is essentially the same as the theory involved in the treatment of combined sewage storm overflow. The major differences are the lower level of solids to be handled, and the requisite effluent water quality. Based on the data contained in Appendix D, indicating that filtration is capable of controlling solids levels to below 10 mg/l, this process may be applicable to situations where a marginal removal of solids and BOD is required to meet water quality criteria. The major potential advantages of the high rate deep bed filter for secondary effluent are: first, due to the high filtration rate, the space requirements, and secondly, because of this high filtration rate, the economics of this process are favorable over shallower filters operating at much lower filtration rates.

Analogous to the approach taken in regard to combined sewage storm overflow filtration, a higher quality product water may be obtained by adding various chemical coagulants prior to the deep bed filter. For example, alum, lime, and possibly iron coagulants and polyelectrolyte, applied in proper combination and dosage, might produce an effluent or product water with low residuals of suspended solids, biochemical oxygen demand, and phosphates. Through the addition of phosphate reducing coagulants (alum, lime, iron salts), it may be possible to compress or eliminate the flocculator-clarifiers or solids contact clarifiers that are normally associated with phosphate removal. In many cases, a filter is required after these units anyway, to reduce phosphate levels to low concentrations.

Based on the preliminary test results contained in Appendix D, a research and development grant was applied for and obtained to evaluate high rate, deep bed filtration in treating secondary effluent from an activated sludge plant.

Under this activated sludge plant secondary effluent testing program (26), the selected media (5 feet - No. 3 Anthracite over 3 feet - No. 612 Sand) for combined sewer overflow treatment was also evaluated in terms of its capability for polishing secondary effluents. Test data has confirmed the applicability of this combined sewer overflow media to reducing suspended solids, BOD, and phosphates to low residuals.

## Urban Runoff Treatment and Sediment Control

Additional areas of application for the deep bed high rate filtration process are in the treatment of urban runoff and also in treating flows from particular rivers for sediment control. As shown in Table B-5 the high rate filtration system was more effective in reducing fixed suspended solids than volatile suspended solids from combined sewer overflows. Since the nature of urban runoff would be similar to that of combined sewer overflows, except that the suspended solids would be of a more fixed or inorganic nature, the proposed treatment system would probably be more effective in treating urban runoff than it would be in handling combined sewer overflow discharges. In regard to sediment control, past data by Hydrotechnic (27) has demonstrated that high rate filters can remove inorganic solids such as those that would normally be associated with erosion. It may be practical to filter discharges of entire rivers which contribute heavily to the sediment problem. This might prove to be a more economical and preferable method of handling the problem than periodic dredging of rivers to maintain navigable channels, since dredging creates a pollution problem.

## Dual Purpose of Utilization of High Rate Filtration Process

In Cleveland, the total duration of the overflows from the combined sewer system is approximately 300 hours per annum. This indicates the possibility of utilizing dual purpose treatment plants based on the high rate filtration process (15). Such installations would treat combined sewer overflows when they occur and in between such periods, for over 95 percent of the time, the filtration process would treat other wastewaters depending on the location of the process.

For a high rate filtration process for combined sewer overflow treatment located in the area of the domestic wastewater treatment plant, the filtration process can be utilized for polishing the treatment plant effluent as well as to protect the effluent quality during plant overloading or process malfunction.

For a newly designed physical-chemical process to treat domestic wastewater, the high rate filtration process can be adopted to handle both dry and wet weather flow, including combined sewer overflows in conjunction with an adequate storage facility.

The economical benefits of such dual purpose utilization of the high rate filtration process should not be overlooked.

## SECTION XIII

## ACKNOWLEDGMENTS

This project was undertaken through sponsorship of the U.S. Environmental Protection Agency.

U.S. Environmental Protection Agency
Office of Research and Monitoring
Municipal Technology Branch
1901 North Fort Meyer Drive
Arlington, Virginia 22209

National Environmental Research Center
Edison Water Quality Research Division
Storm and Combined Sewer Technology Branch
Edison, New Jersey 08817

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The project testing program was conducted in Cleveland, Ohio.

City of Cleveland
Department of Public Utilities
Division of Water Pollution Control
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Cleveland, Ohio 44114

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Cleveland, Ohio 44125

Acknowledgment is made to Mr. C.A. Crown, Commissioner of the Division of Water Pollution Control, and Mr. Ray Roth, Assistant Commissioner of Southerly Wastewater Pollution Control Center for providing the pilot plant site. Thanks are due to Messrs. Nabil Ghoubriel, Superintendent, other members of the staff of the Southerly Wastewater Treatment Plant, and former Director Mr. W. Tresville for their assistance with background information. Thanks are also due to Messrs. E. Martin, E. Newbauer and J.N. Donahue, who supported this project as members of the city's Clean Water Task Force.

The project was conducted by the consulting engineering firm.

Hydrotechnic Corporation
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New York, N.Y. 10022

The project was conceived by Mr. Ross Nebolsine, President, who provided general guidance and high level review throughout its duration. General consultation and review was also provided by Mr. Ivan Pouschine, Jr., Vice President and Mr. Albert S. Toth, Vice President.

The project was managed for most of its duration by Patrick J. Harvey, Division Engineer, who also prepared the draft report.

In the initial project stages, including engineering and construction of the pilot plant facilities, this assignment was managed by Mr. Harold J. Kohlmann, Manager Engineer. Mr. Chi-Yuan Fan, Principal Engineer, was in charge of the daily technical aspects of the project, supervising a field team and an office staff. On site field testing was directed by Mr. George Vercelli, Senior Engineer, and later by Mr. Rey Morales, Engineer.

A special note of acknowledgment is due Dr. John C. Eck, who served as a consultant to Hydrotechnic Corporation on this project.

# SECTION XIV

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R. Nebolsine and J.C. Eck, "Tertiary Treatment of Sewage by the Ultra High Rate Filtration Process," Paper presented at 44th Annual Meeting of the New York Water Pollution Control Association, New York, January 1972.

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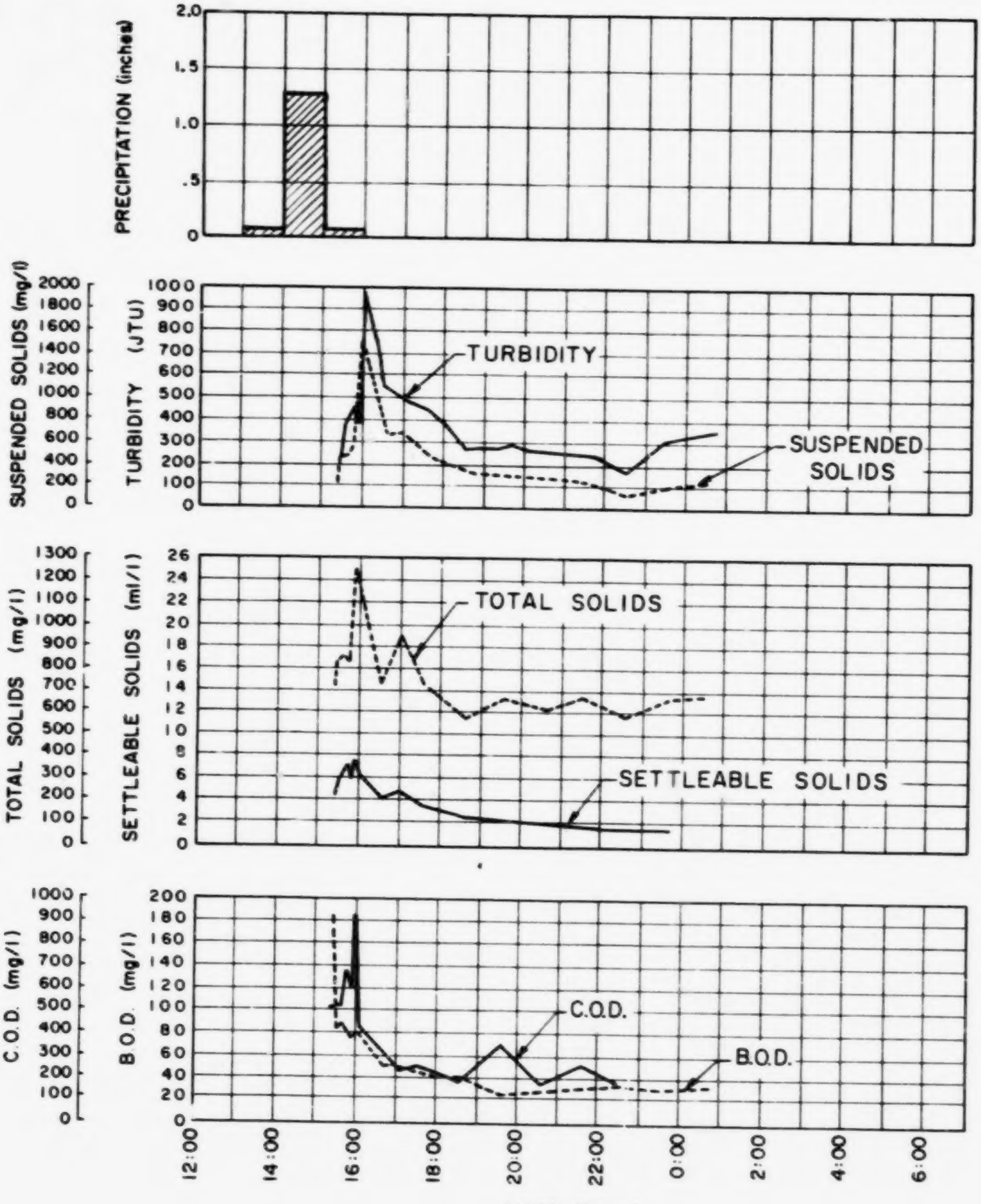

**COMBINED SEWER OVERFLOW CHARACTERISTICS**

7/29/70 DAILY PRECIPITATION 1.26 INCHES

FIGURE A1

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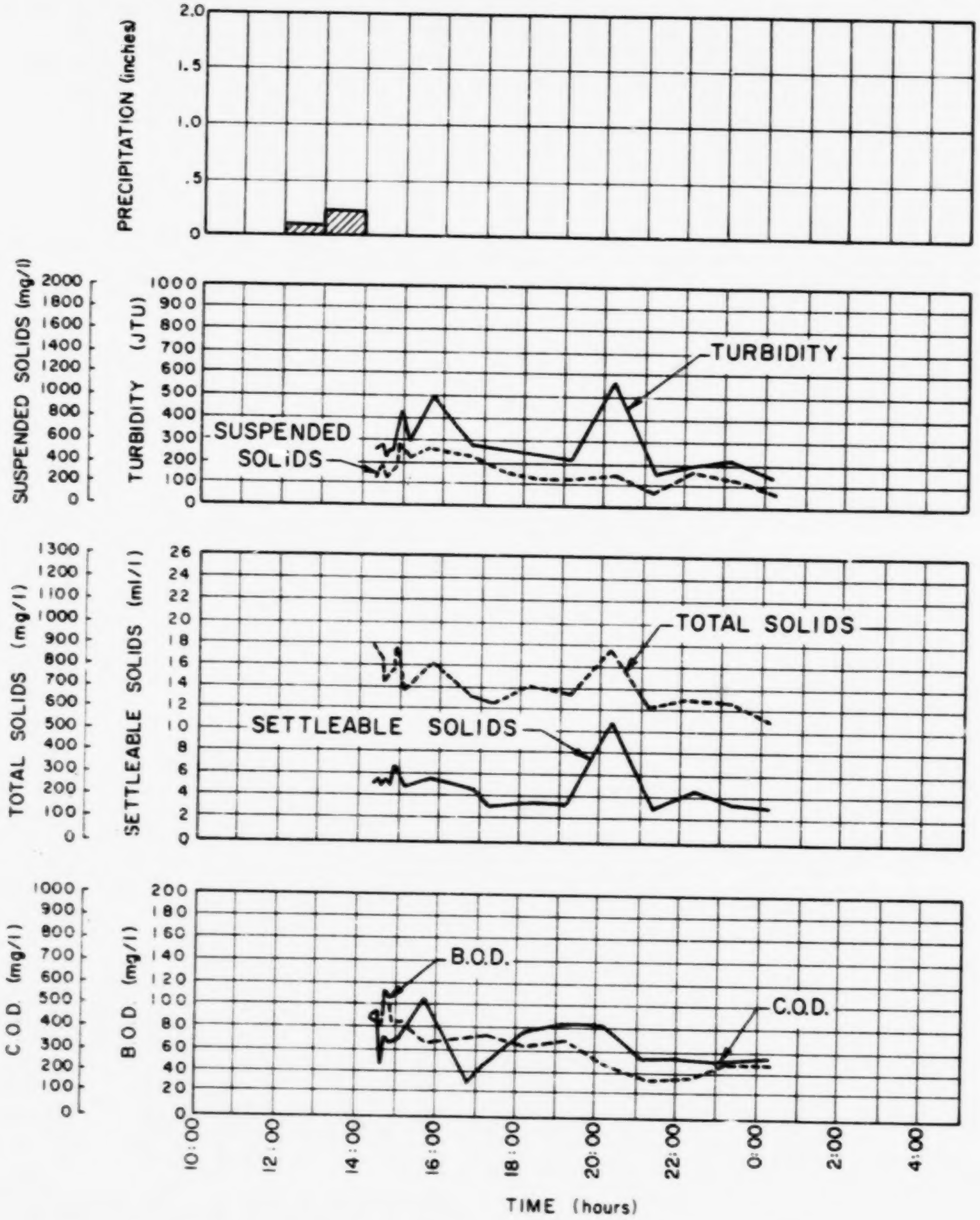
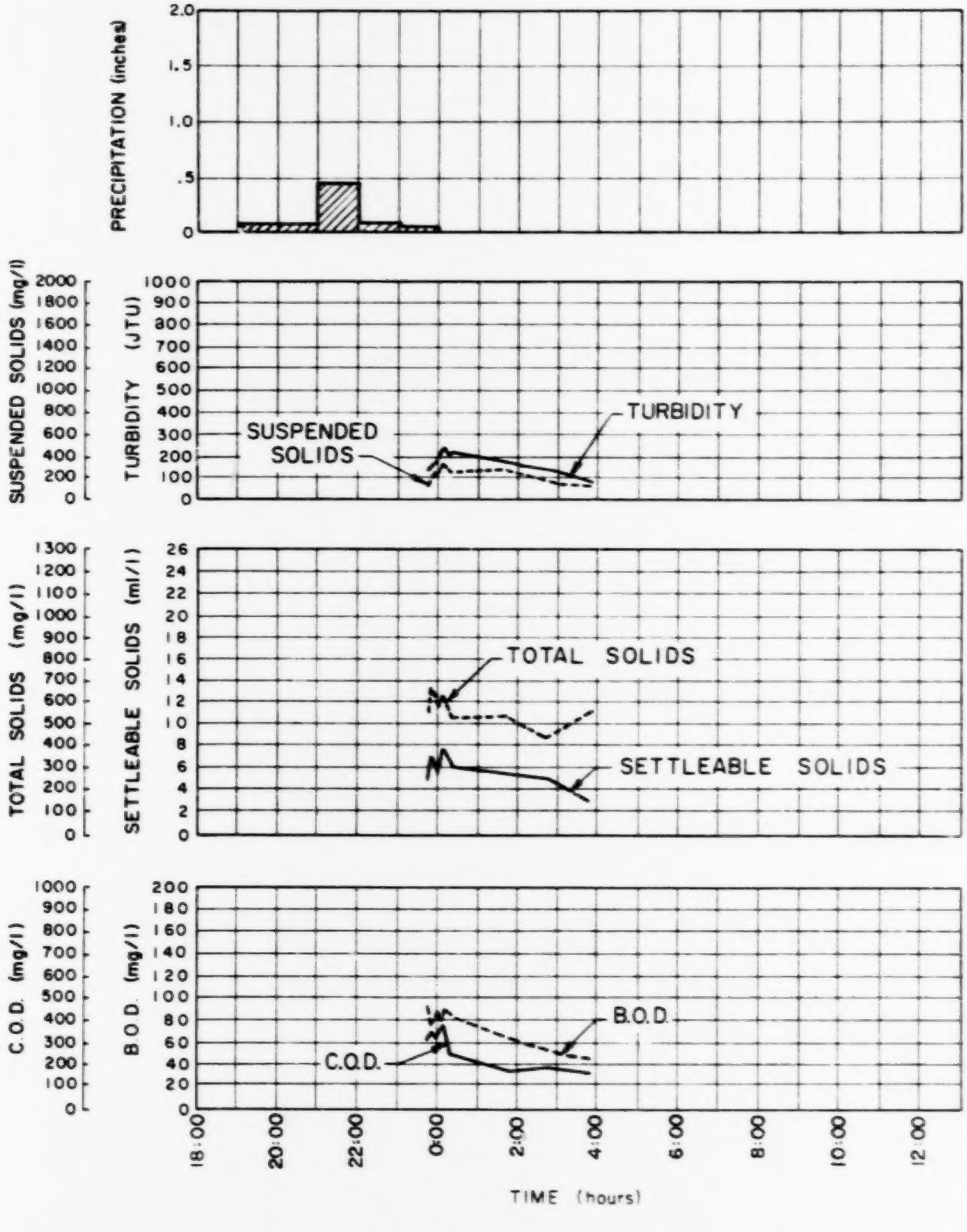


## COMBINED SEWER OVERFLOW CHARACTERISTICS

8/19/70 DAILY PRECIPITATION 0.31 INCHES

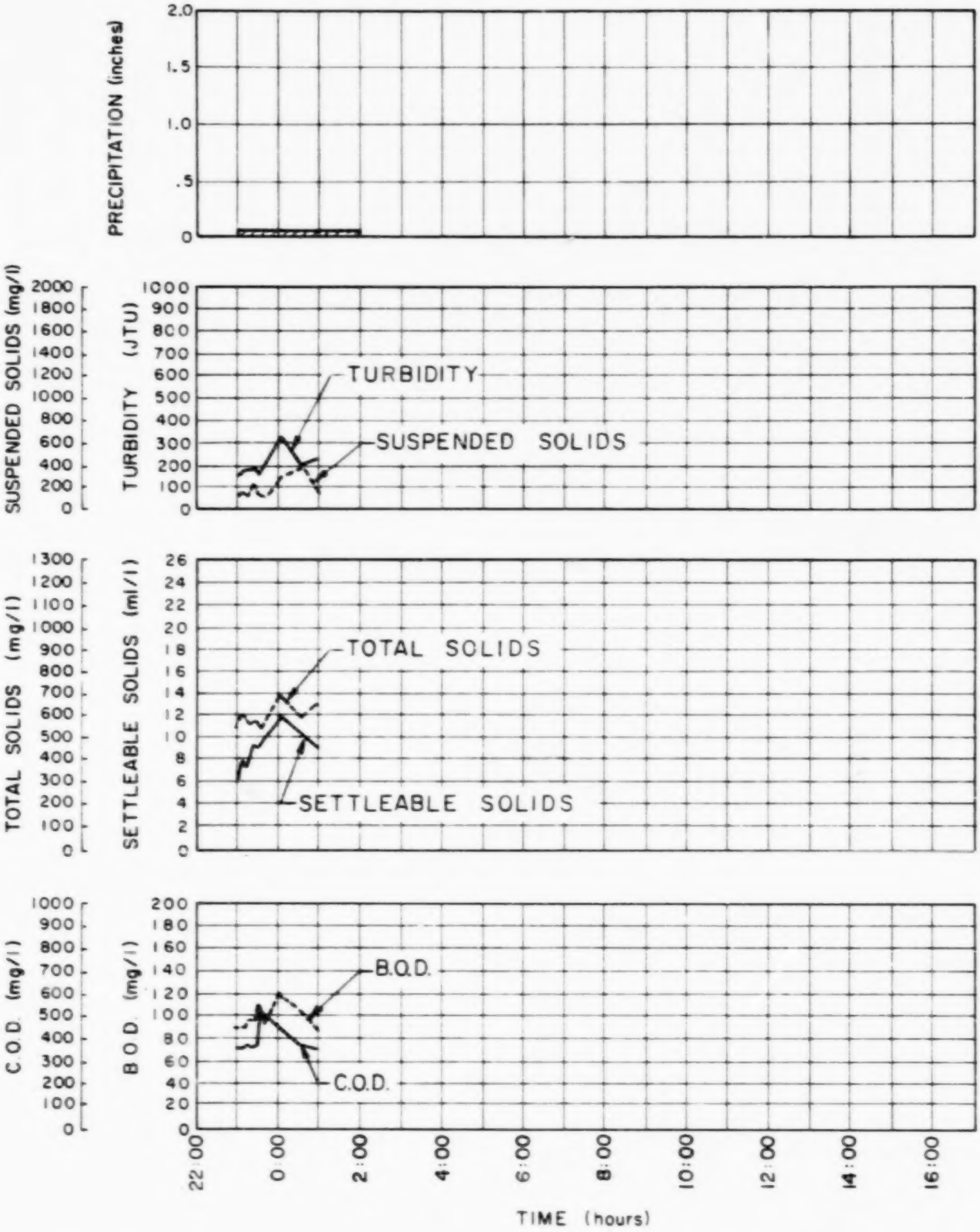
FIGURE A 2



## COMBINED SEWER OVERFLOW CHARACTERISTICS

**8/22/70 DAILY PRECIPITATION 0.56 INCHES**

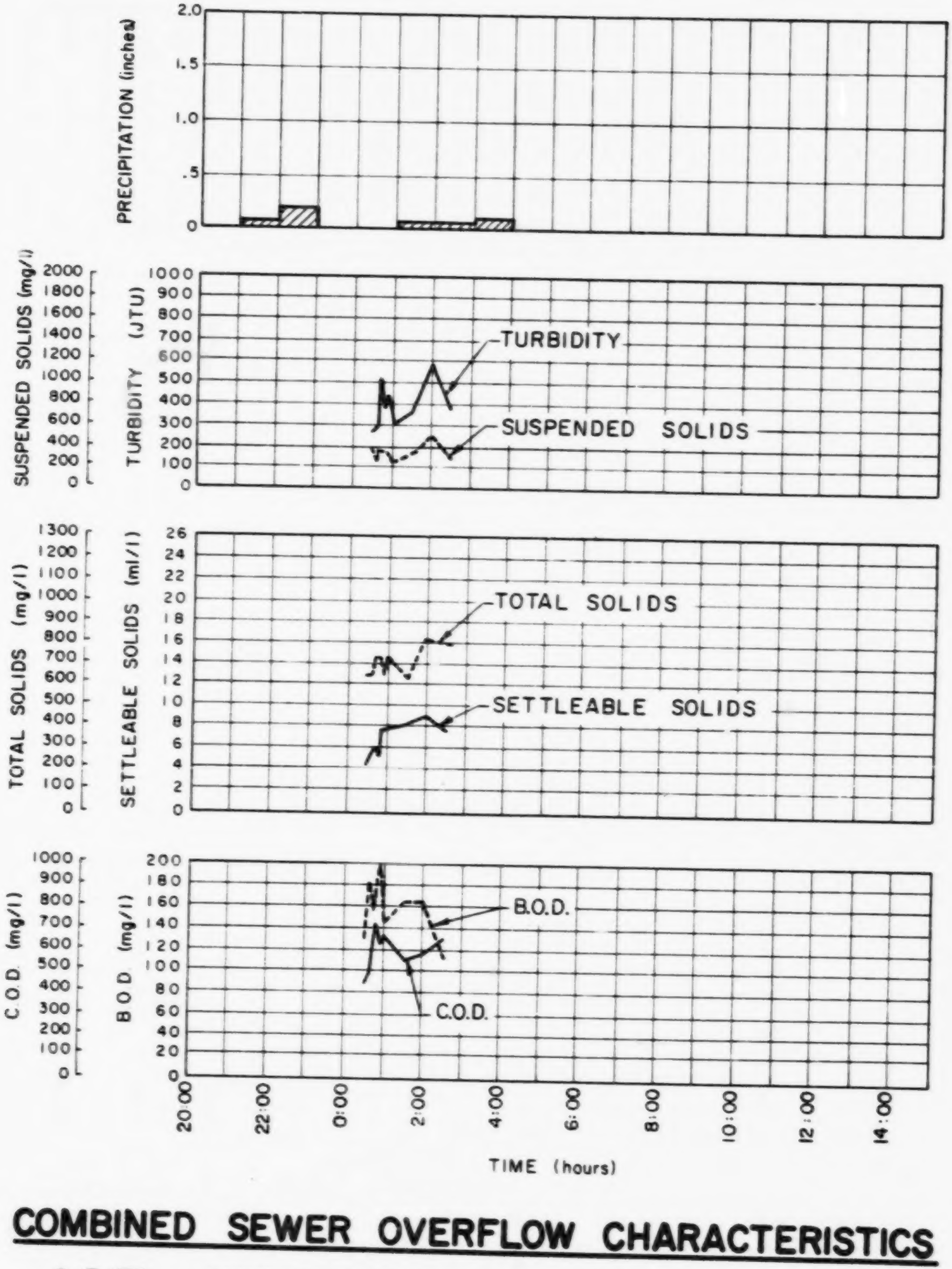
**FIGURE A 3**



## COMBINED SEWER OVERFLOW CHARACTERISTICS

8/30/70 DAILY PRECIPITATION < 0.05 INCHES

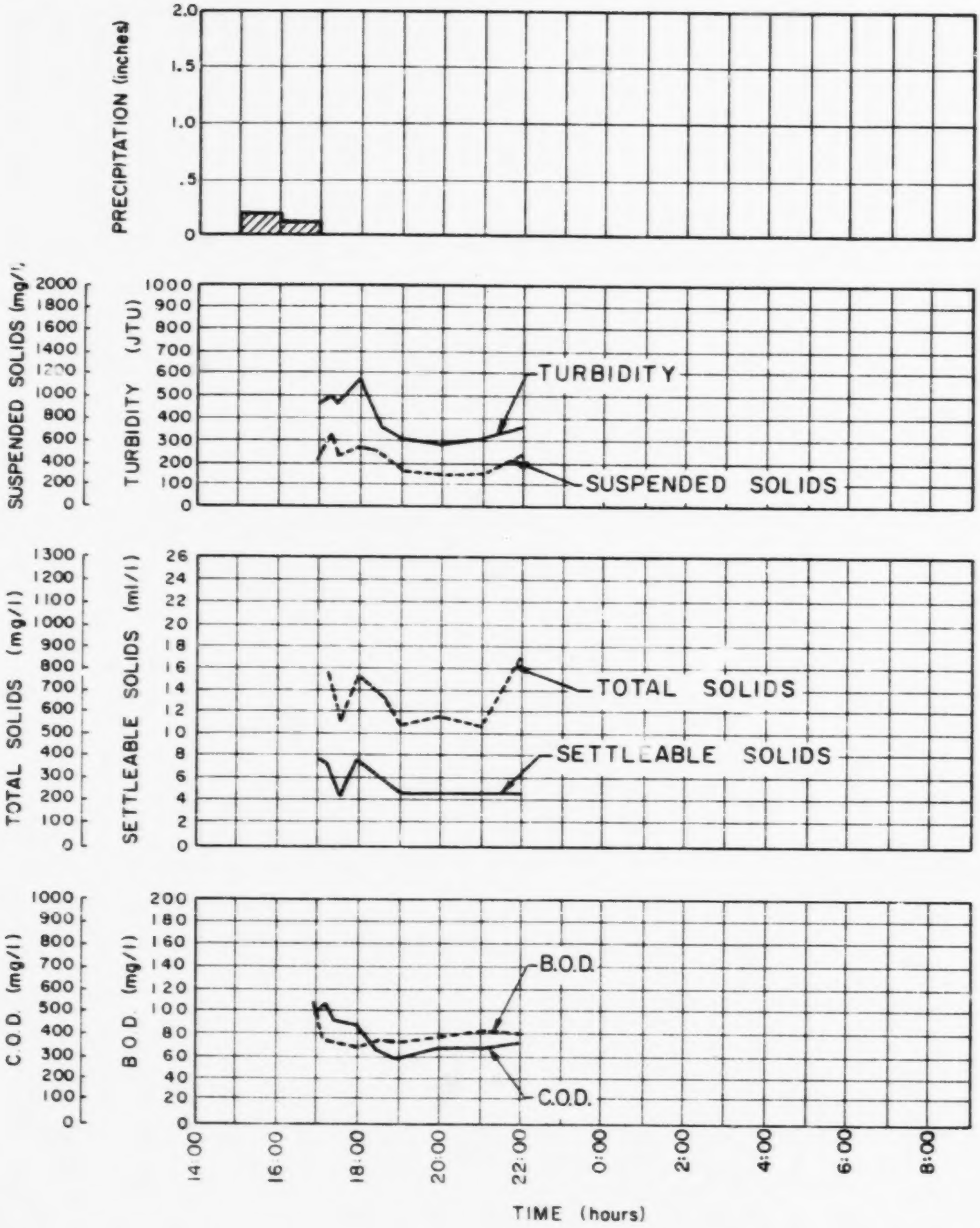
**FIGURE A 4**



## COMBINED SEWER OVERFLOW CHARACTERISTICS

9/3/70 DAILY PRECIPITATION 0.14 INCHES

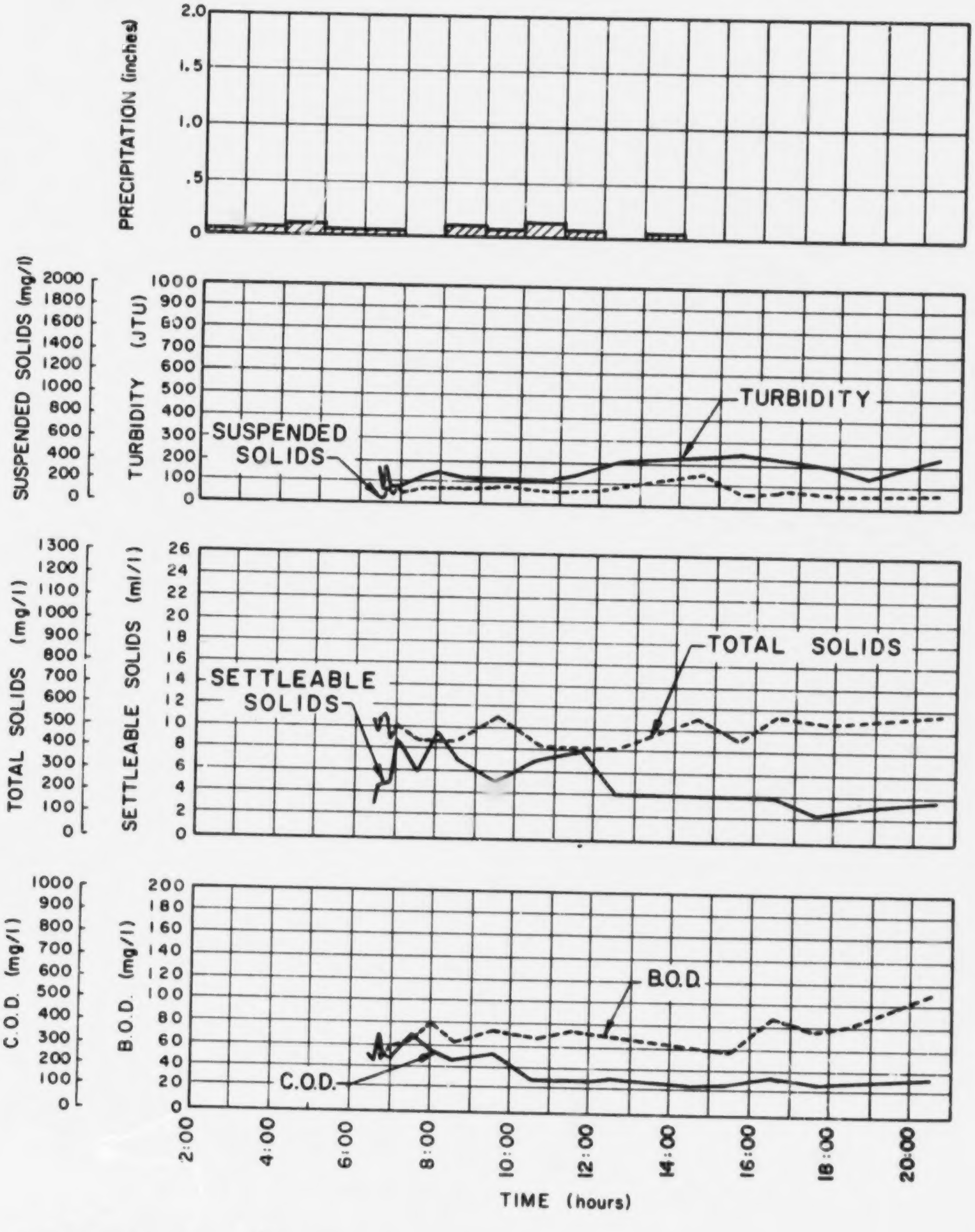
**FIGURE A 5**



## COMBINED SEWER OVERFLOW CHARACTERISTICS

9/8/70 DAILY PRECIPITATION 0.22 INCHES

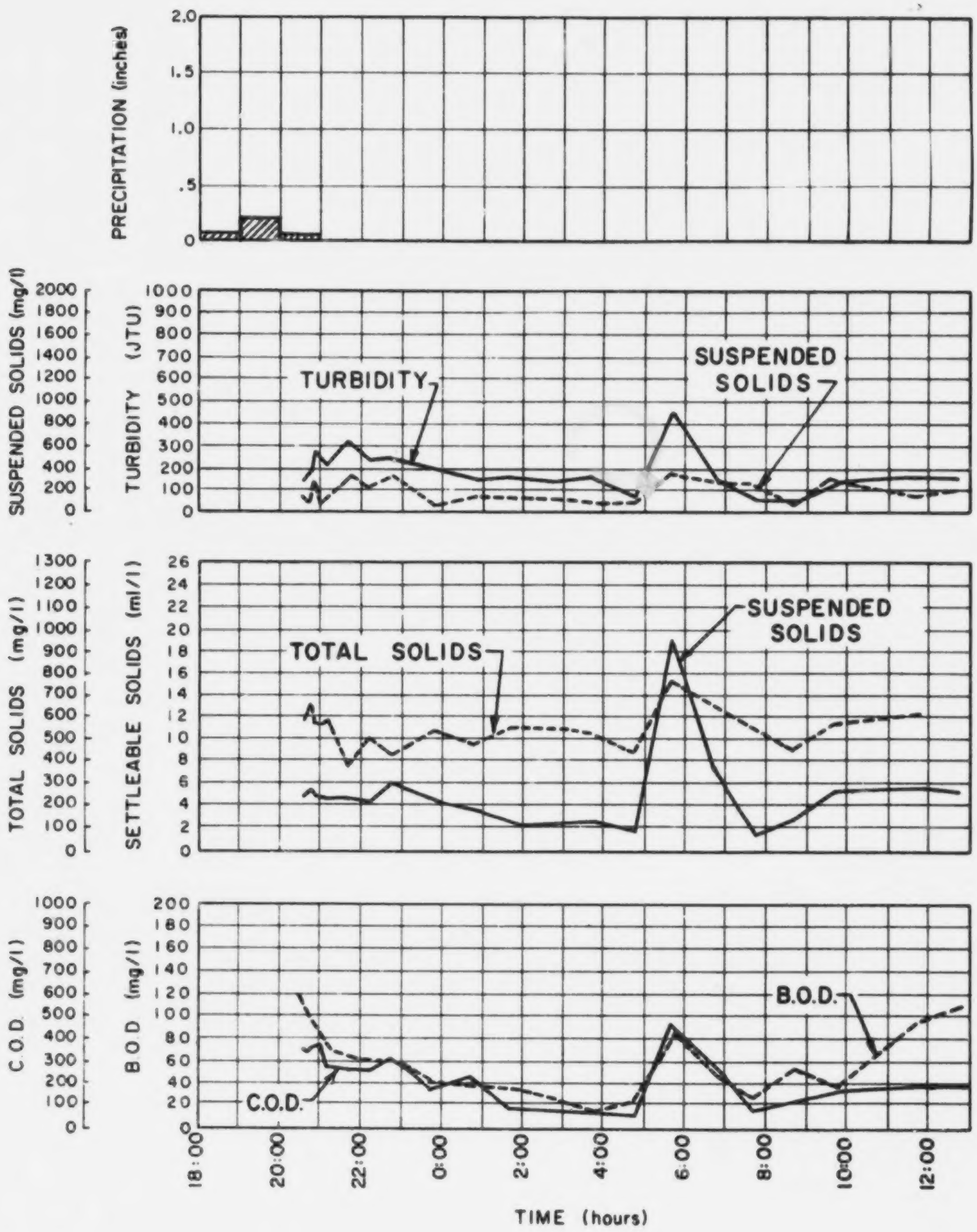
FIGURE A 6



**COMBINED SEWER OVERFLOW CHARACTERISTICS**

9/18/70 DAILY PRECIPITATION 0.51 INCHES

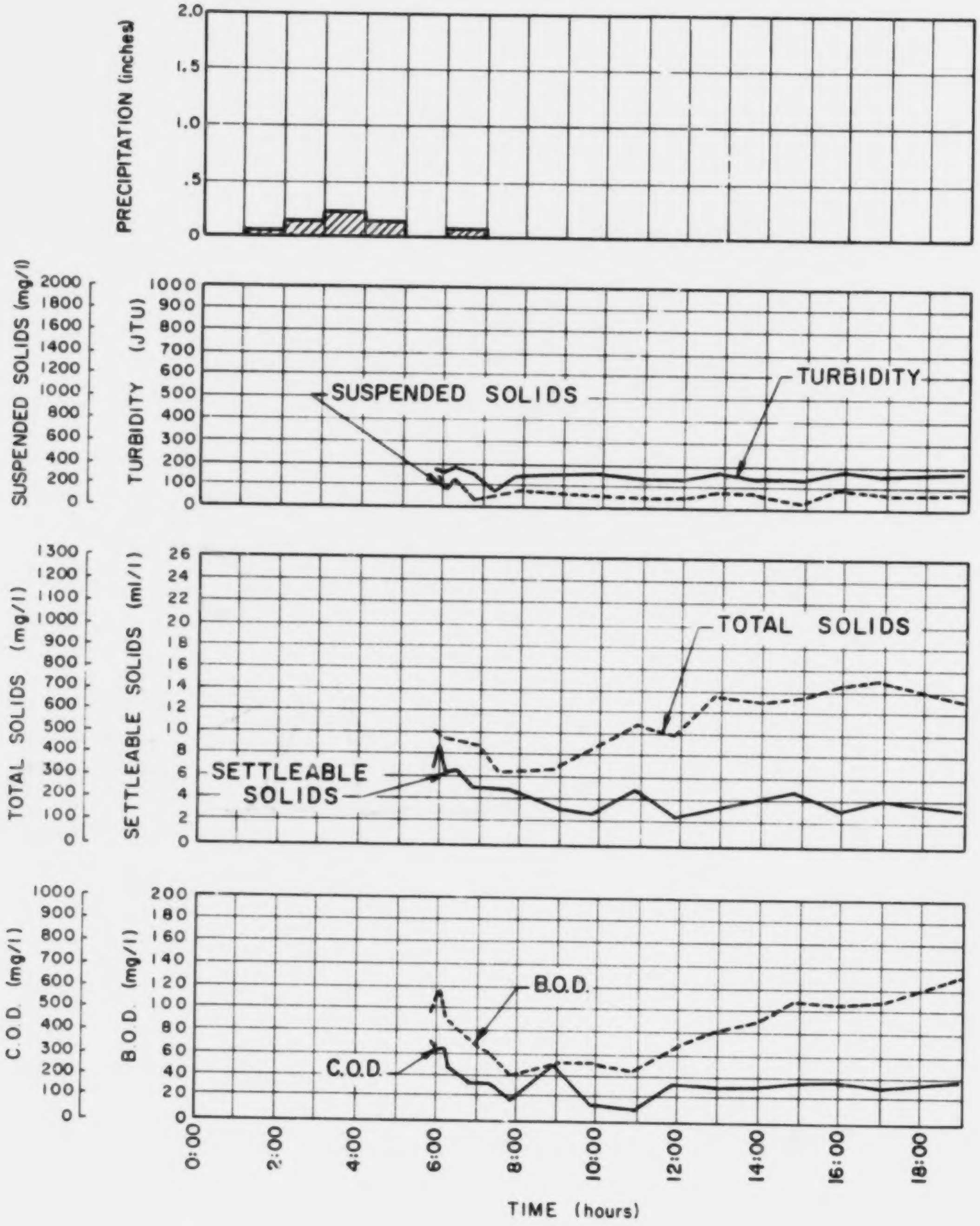
FIGURE A 7



## COMBINED SEWER OVERFLOW CHARACTERISTICS

9/23/70 DAILY PRECIPITATION 0.18 INCHES

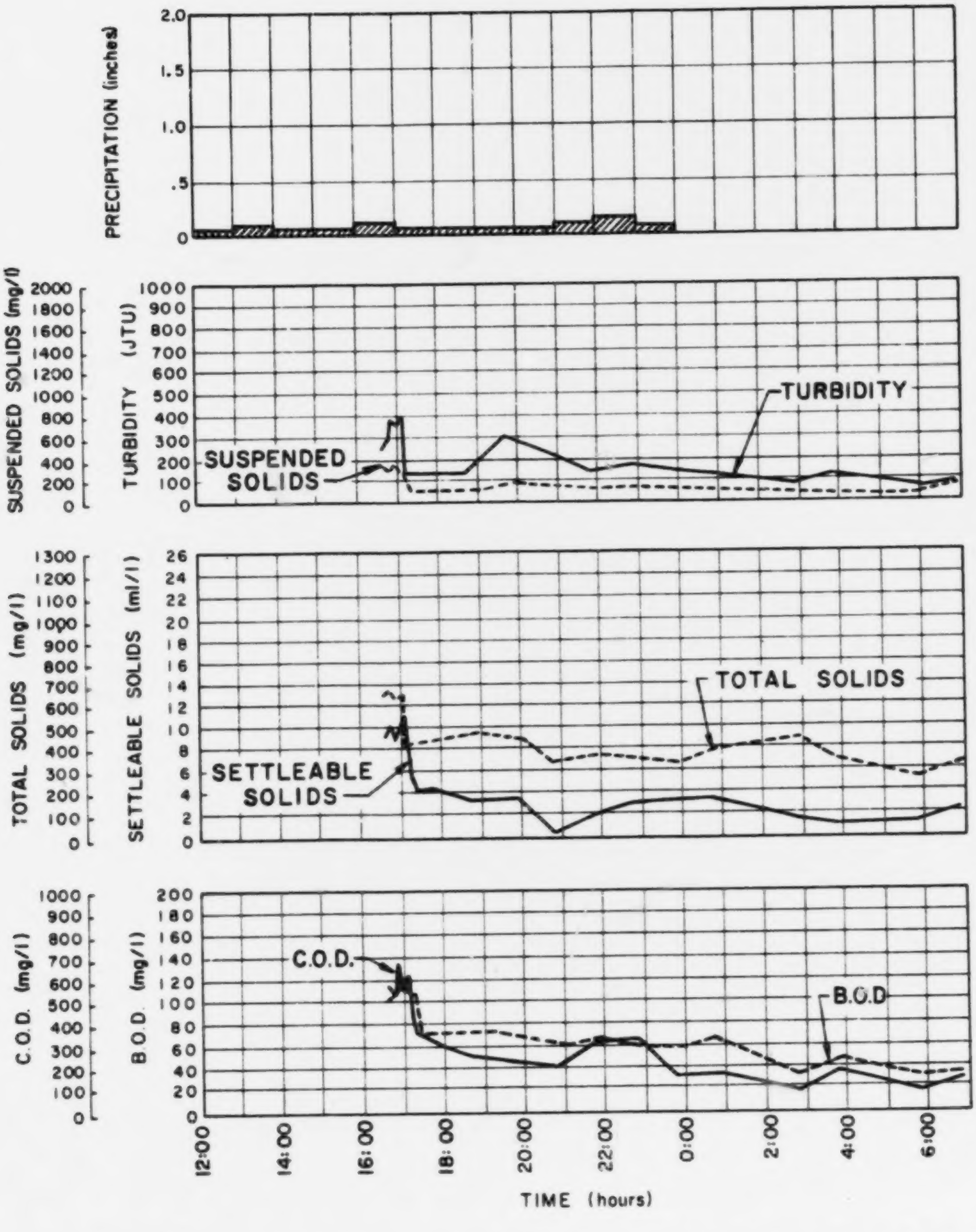
**FIGURE A 8**



## COMBINED SEWER OVERFLOW CHARACTERISTICS

10/6/70 DAILY PRECIPITATION 0.63 INCHES

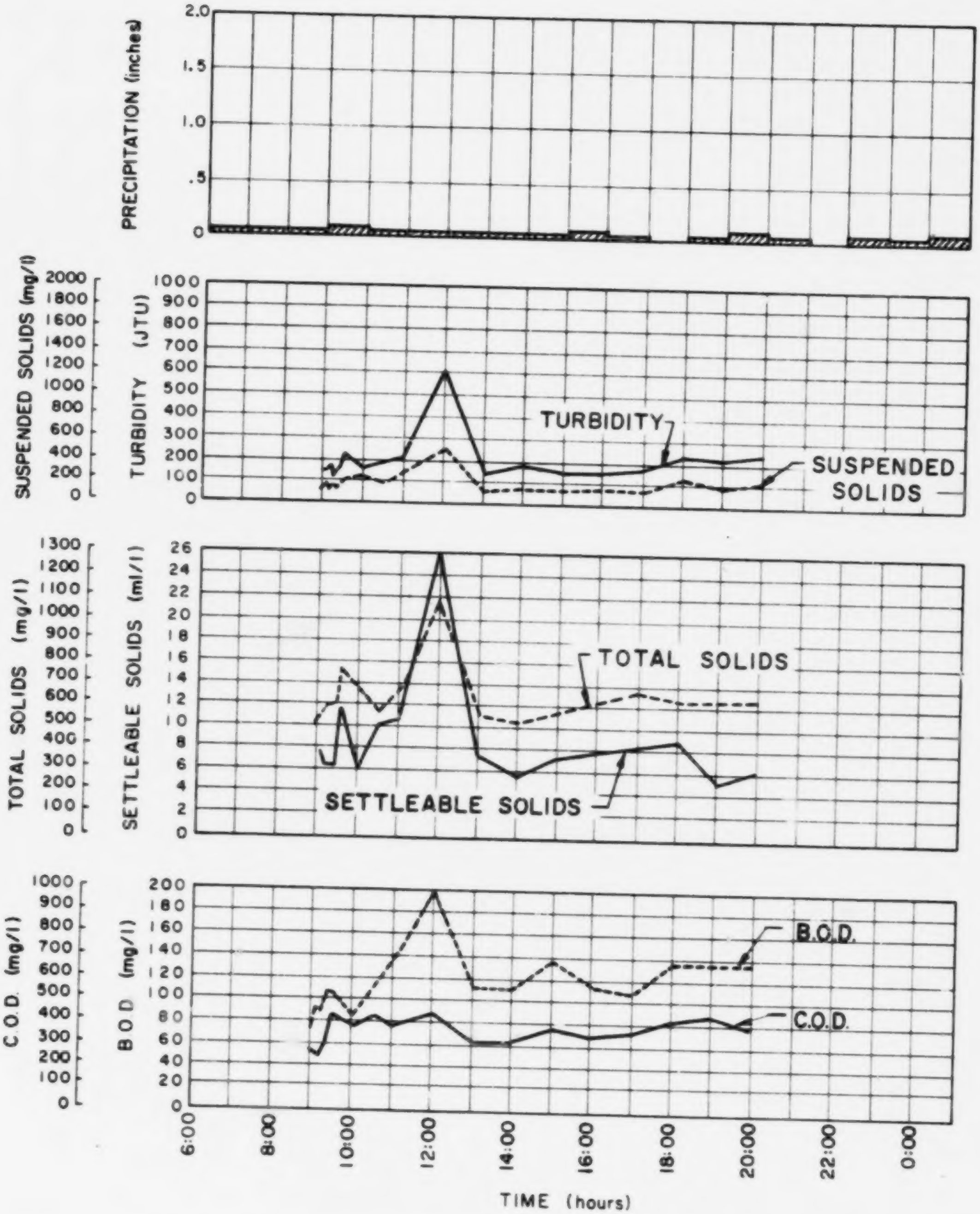
**FIGURE A 9**



## COMBINED SEWER OVERFLOW CHARACTERISTICS

10/12/70 DAILY PRECIPITATION 0.54 INCHES

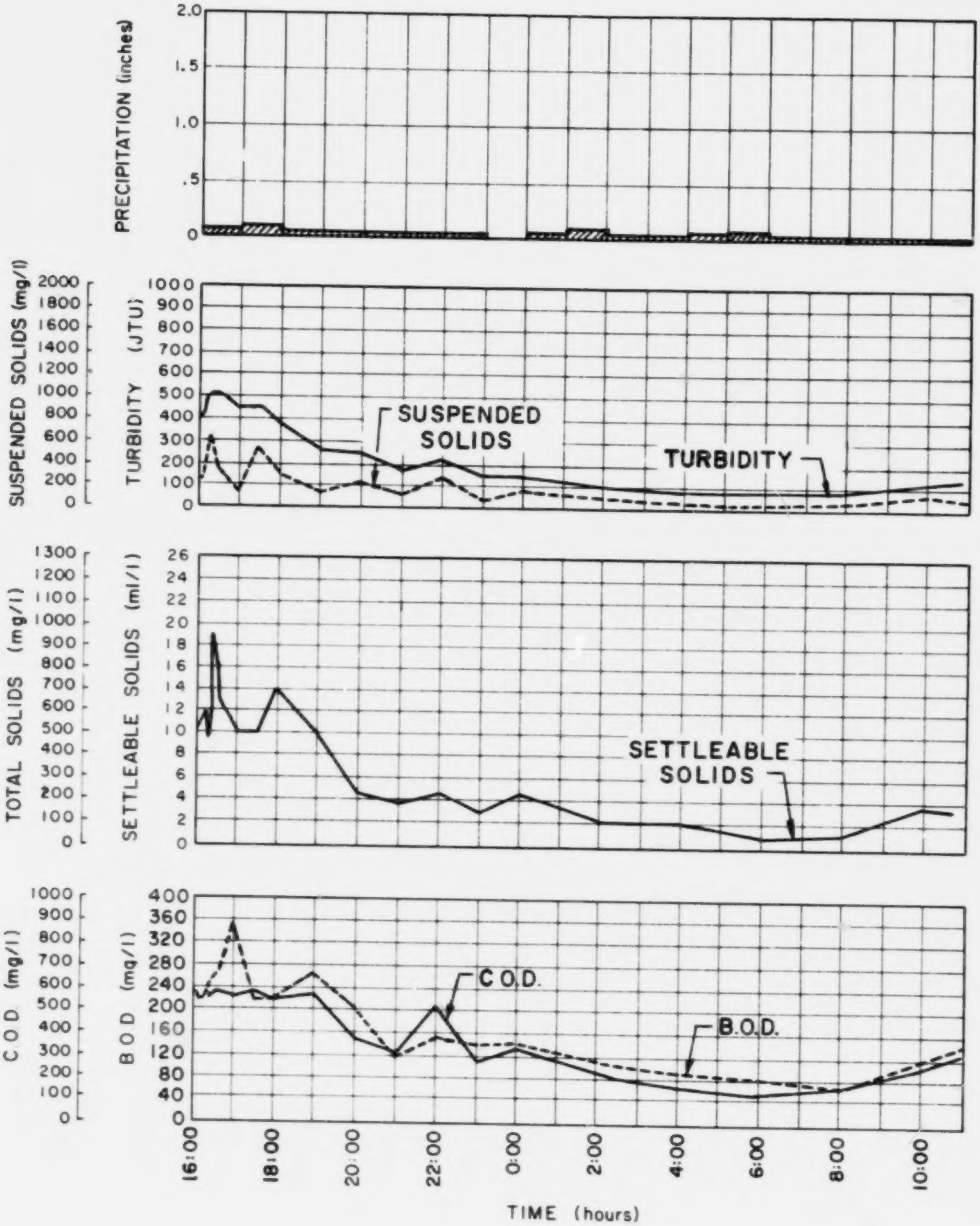
FIGURE A 10



## COMBINED SEWER OVERFLOW CHARACTERISTICS

10/21/70 DAILY PRECIPITATION 0.21 INCHES

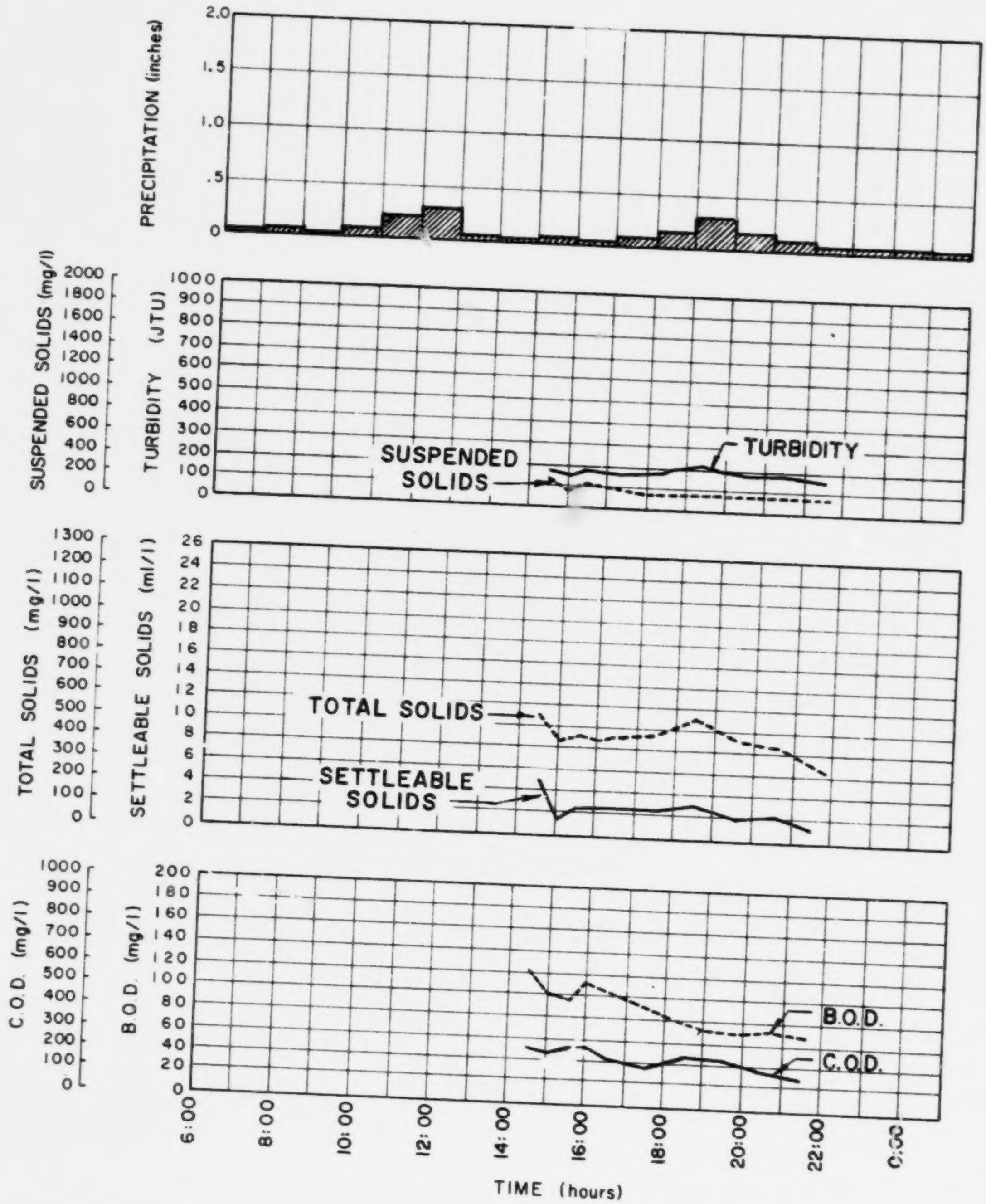
FIGURE A II



## COMBINED SEWER OVERFLOW CHARACTERISTICS

10/29/70 DAILY PRECIPITATION 0.22 INCHES

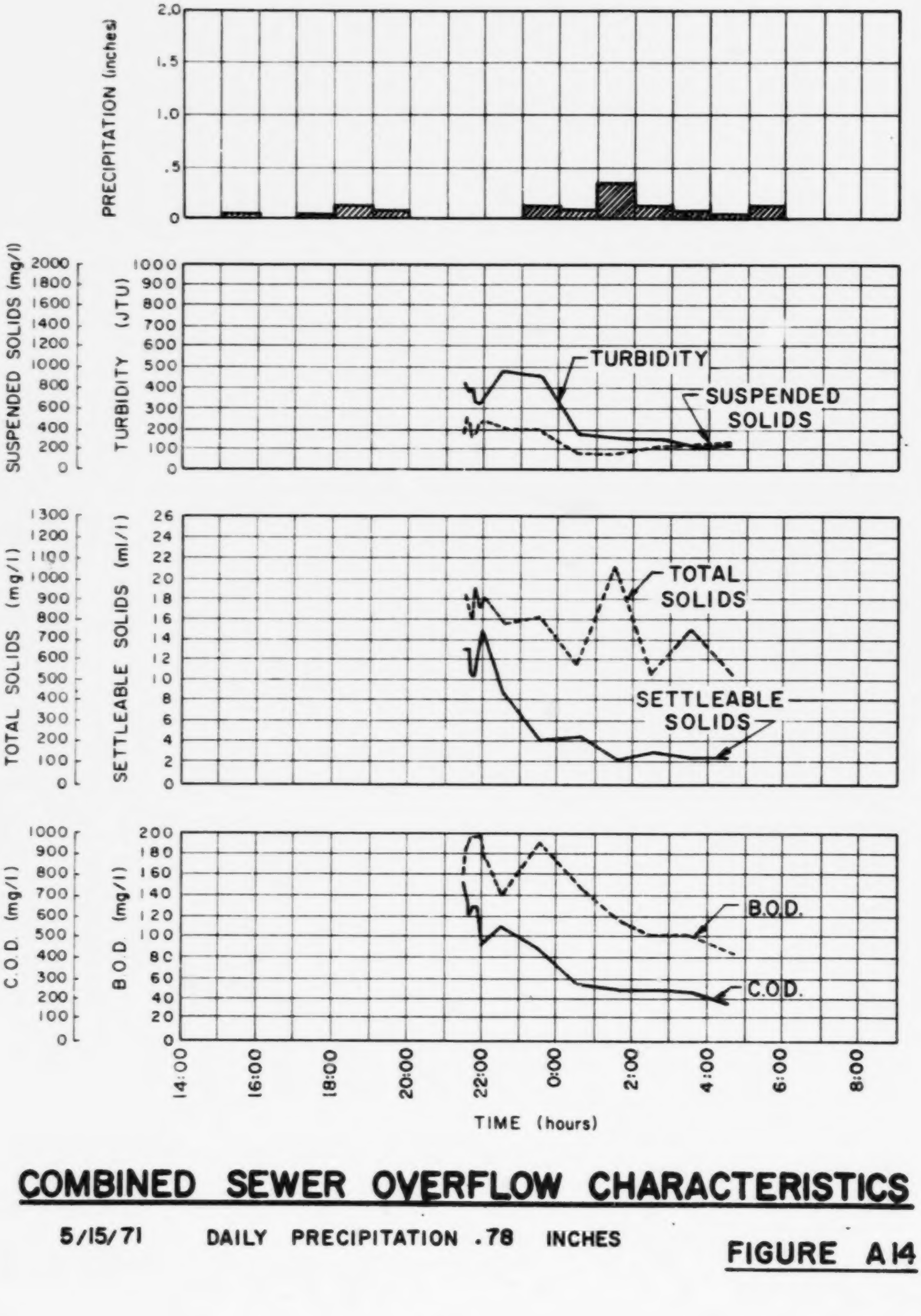
FIGURE A12



COMBINED SEWER OVERFLOW CHARACTERISTICS

11/2/70 DAILY PRECIPITATION 1.47 INCHES

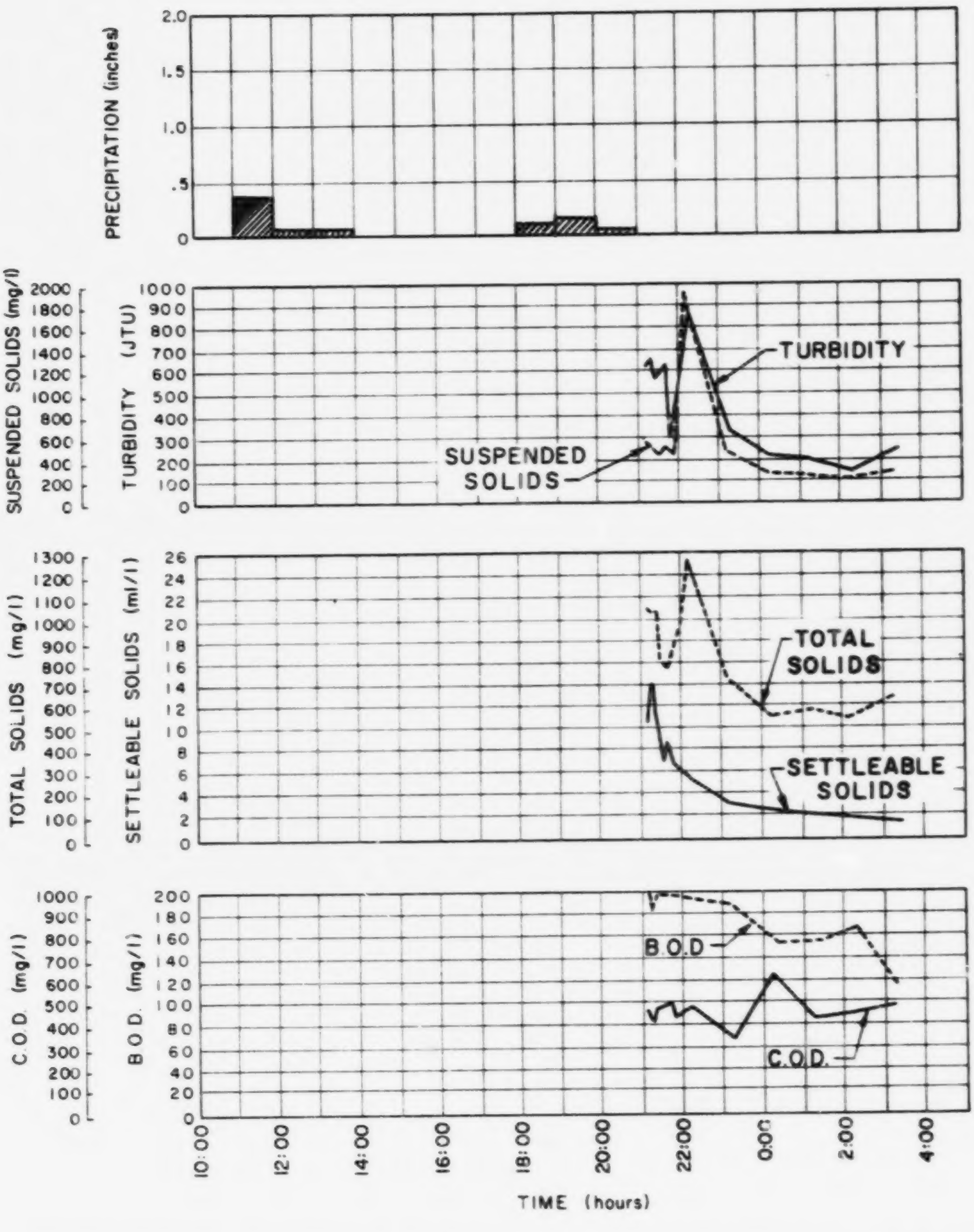
FIGURE A 13



# COMBINED SEWER OVERFLOW CHARACTERISTICS

5/15/71 DAILY PRECIPITATION .78 INCHES

**FIGURE A14**



## COMBINED SEWER OVERFLOW CHARACTERISTICS

6/7/71 DAILY PRECIPITATION 0.47 INCHES

FIGURE A15

# TABLE B-1 (SHEET No.1)

# COMBINED SEWER OVERFLOW FILTRATION TESTS

# SYSTEM PERFORMANCE

(1970 TEST DATA)

| | Screen | Filter | | | % Removal of Contaminents by Screen and Filter | | | | |
|---|---|---|---|---|---|---|---|---|---|
| Run No. | Size (Mesh) | Media | Flux Rate (gpm/ft$^2$) | Poly Feed (mg/l) | Suspended Solids | Settleable Solids | B. O. D. | C. O. D. | Fecal Coliform |
| 4SF II | 20 | 48"#4 Anth.**<br>36"#612 Sand | 24 | 0 | 60.7 | 86.4 | 22.3 | 59.6 | 52.0 |
| 4SF III | 20 | 48"#3 Anth.**<br>36"#612 Sand | 24 | 0 | 59.2 | 82.7 | 26.3 | 59.6 | 52.0 |
| 5SF I* | 20 | 48"#4 Anth.**<br>36"#612 Sand | 16 | 0 | 60.6 | 77.6 | 35.4 | 56.9 | - |
| 5SF II* | 20 | 48"#4 Anth.**<br>36"#612 Sand | 16 | 0 | 75.9 | 86.5 | 39.2 | 58.8 | - |
| 5SF III* | 20 | 48"#3 Anth.<br>36"#612 Sand | 16 | 0 | 63.4 | 85.9 | 24.1 | 46.5 | |
| 6SF I | 20 | 48"#3 Anth.<br>36"#612 Sand | 24 | 0 | 71.1 | 88.5 | 39.5 | 28.5 | 71.4 |
| 6SF III | 20 | 60"#3 Anth.<br>36"#612 Sand | 16 | 0 | 83.1 | 94.1 | 53.2 | 34.5 | 64.2 |
| 7SF III | 40 | 60"#3 Anth.<br>36"#612 Sand | 16 | 0 | 31.5 | 86.7 | 25.5 | 35.9 | - |
| 8SF I | 40 | 60"#3 Anth.<br>36"#612 Sand | 32 | 0 | 55.1 | 69.1 | 23.4 | 77.0 | - |
| 9SF I | 40 | 48"#3 Anth.<br>36"#612 Sand | 24 | 0 | 46.4 | 75.3 | 22.7 | 48.3 | 34.7 |
| 9SF II | 40 | 48"#3 Anth.<br>36"#612 Sand | 40 | 0 | 48.4 | 81.6 | 22.6 | 56.5 | 78.0 |
| 9SF III | 40 | 60"#3 Anth.<br>36"#612 Sand | 10 | 0 | 77.5 | 98.5 | 43.8 | 72.5 | 87.1 |
| 9ASF III | 40 | 60"#3 Anth.<br>36"#612 Sand | 40 | 0 | 31.9 | 90.5 | 49.8 | 41.5 | 86.7 |
| 10SF I | 40 | 48"# 3 Anth.<br>36"#612 Sand | 32 | 0 | 63.7 | 85.0 | 76.9 | 39.3 | 40.7 |
| 10SFII | 40 | 48"#3 Anth.<br>36"#612 Sand | 16 | 0 | 83.0 | 82.1 | 20.1 | 50.5 | 65.4 |
| 10SF III | 40 | 60"#3 Anth.<br>36"#612 Sand | 24 | 0 | 71.9 | 87.3 | 33.9 | 48.0 | 74.1 |
| 10ASF III | 40 | 60"#3 Anth.<br>36"#612 Sand | 24 | .5 | 81.3 | 85.6 | 10.8 | 53.8 | 87.6 |
| 11SF I | 40 | 48"#3 Anth.<br>36"#612 Sand | 32 | .5 | 52.7 | 87.1 | 14.9 | 52.8 | 14.6 |
| 11SF II | 40 | 48"#3 Anth.<br>36"#612 Sand | 16 | 2.0 | 68.1 | 93.7 | 35.9 | 58.9 | 29.0 |
| 11SFIII | 40 | 60"#3 Anth.<br>36"#612 Sand | 24 | 2.0 | 66.6 | 99.2 | 33.1 | 57.5 | 33.3 |
| 13SF II | 40 | 48"#3 Anth.<br>36"#612 Sand | 24 | 1.5 | 64.3 | 90.1 | 24.3 | 43.5 | - |
| 13SF III | 40 | 48"#3 Anth.<br>36"# 612 Sand | 16 | 1.5 | 74.7 | 95.7 | 32.3 | 51.5 | - |
| 13SF IV | 40 | 48"#3 Anth.<br>36"# 612 Sand | 10 | 1.5 | 79.3 | 95.4 | 33.3 | 54.4 | - |
| 14SF I | 40 | 48"#3 Anth.<br>36"#612 Sand | 16 | .5 | 63.8 | 94.1 | 31.2 | 36.8 | 43.9 |
| 14ASF I | 40 | 48"#3 Anth.<br>36"#612 Sand | 32 | .5 | 67.1 | 95.2 | 33.6 | 16.1 | 48.7 |

* Results of Screen Performance Were Based on Previous Filter Run

** Filter Columns Plugged

NOTE: RESULTS OF SCREEN PERFORMANCE WERE BASED ON 1970 TESTING DATA

# TABLE B-1 (SHEET No.2)

# COMBINED SEWER OVERFLOW FILTRATION TESTS

# SYSTEM PERFORMANCE

## (1971 TEST DATA)

| | Screen | Filter | | | | % Removal of Contaminants by Screen and Filter | | | |
|---|---|---|---|---|---|---|---|---|---|
| Run No. | Size (Mesh) | Media | Flux Rate (gpm/ft$^2$) | Poly Feed (mg/l) | Coagulant Feed (mg/l) | Suspended Solids | Settleable Solids | B. O. D. | C. O. D. |
| 17SF II | 40 | 60" NO. 3 ANTHRACITE / 36" NO. 612 SAND | 10 | 0 | 0 | 77.6 | 95.5 | 11.0 | 52.1 |
| 17SF III | 40 | | 16 | 0 | 0 | 72.8 | 94.6 | 19.2 | 56.8 |
| 17SF IV | 40 | | 24 | 0 | 0 | 62.2 | 94.8 | 35.3 | 49.7 |
| 18SF II | 40 | | 8 | Atlas 4A4<br>1.0 | 0 | 67.7 | 97.5 | 41.7 | 35.0 |
| 18SF III | 40 | | 24 | Atlas 4A4<br>1.0 | 0 | 38.6 | 88.8 | 37.9 | 41.1 |
| 18SF IV | 40 | | 16 | Atlas 4A4<br>1.0 | 0 | 41.3 | 85.2 | 16.9 | - |
| 19SF III | 40 | | 8 | Mag.560C<br>1.0 | Alum<br>30.0 | 72.8 | 97.8 | 23.7 | 53.9 |
| 19SF IV | 40 | | 16 | Mag.560C<br>1.0 | Alum<br>30.0 | 56.9 | 91.2 | 23.2 | - |
| 19ASF II | 40 | | 24 | Mag.560C<br>1.0 | Alum<br>30.0 | 81.0 | 93.8 | 31.8 | 60.3 |
| 19ASF IV | 40 | | 32 | Mag.560C<br>1.0 | Alum<br>30.0 | 64.4 | 91.7 | 39.1 | 65.8 |
| 19BSF II | 40 | | 16 | 0 | Alum<br>30.0 | 51.8 | 60.0 | 26.2 | 32.6 |
| 19BSF IV | 40 | | 16 | Mag.560C<br>1.0 | Alum<br>30.0 | 56.9 | 76.7 | 38.3 | 59.5 |
| 19CSF II | 40 | | 16 | Herc.836<br>1.0 | Alum<br>30.0 | 59.8 | 76.0 | 29.5 | 74.4 |
| 19CSF IV | 40 | | 16 | Herc.836<br>1.0 | Alum<br>30.0 | 72.9 | 78.3 | 53.8 | 38.7 |
| 20SF II | 40 | | 24 | Atlas 4A4<br>1.0 | $FeCl_3$ 25.0 | 58.2 | 93.8 | - | - |
| 20SF III | 40 | | 16 | Atlas 4A4<br>1.0 | $FeCl_3$ 25.0 | 83.4 | 93.9 | 37.1 | 47.2 |
| 20SF IV | 40 | | 8 | Atlas 4A4<br>1.0 | $FeCl_3$ 25.0 | 92.2 | 93.8 | 41.9 | 71.6 |
| 20ASF II | 40 | | 16 | Atlas 4A4<br>1.0 | Alum<br>30.0 | 71.0 | 89.6 | 40.6 | 76.4 |
| 20ASF III | 40 | | 16 | Atlas 4A4<br>1.0 | Alum<br>30.0 | 65.5 | 86.1 | 39.8 | 61.5 |
| 21SF III | 40 | | 8 | Swift X-400<br>1.0 | Alum<br>30.0 | 67.8 | 95.3 | 54.7 | 74.4 |
| 21SF IV | 40 | | 16 | Swift X-400<br>1.0 | Alum<br>30.0 | 49.0 | - | 28.0 | 61.5 |
| 21ASF II | 40 | | 8 | Swift X-400<br>1.0 | Alum<br>30.0 | 56.0 | - | 52.0 | 61.5 |
| 21ASF III | 40 | | 24 | Swift X-400<br>1.0 | Alum<br>30.0 | 54.8 | 95.0 | 58.3 | 64.5 |

NOTE: RESULTS OF SCREEN PERFORMANCE WERE BASED ON 1970 TESTING DATA

# TABLE B-1 (SHEET No.3)
# COMBINED SEWER OVERFLOW FILTRATION TESTS
# SYSTEM PERFORMANCE
### (1971 TEST DATA)

| | Screen | Filter | | | | % Removal of Contaminants by Screen and Filter | | | |
|---|---|---|---|---|---|---|---|---|---|
| Run No. | Size (Mesh) | Media | Flux Rate (gpm/ft$^2$) | Poly Feed (mg/l) | Coagulant Feed (mg/l) | Suspended Solids | Settleable Solids | B. O. D. | C. O. D. |
| 22SF II | 40 | 60" NO. 3 ANTHRACITE / 36" NO. 612 SAND | 8 | SwiftX-400<br>1.0 | Alum<br>30.0 | 82.4 | 98.1 | 65.5 | 70.8 |
| 22SF III | 40 | | 16 | SwiftX-400<br>1.0 | Alum<br>30.0 | 83.1 | 91.3 | 63.3 | 64.1 |
| 22SF IV | 40 | | 24 | SwiftX-400 | Alum<br>30.0 | 81.9 | 84.4 | 63.5 | 61.4 |
| 22ASFII | 40 | | 8 | Atlas 3A3<br>1.0 | Alum<br>30.0 | 82.6 | 93.3 | - | - |
| 22ASF III | 40 | | 16 | Atlas 3A3<br>1.0 | Alum<br>30.0 | 61.2 | 82.4 | 50.9 | - |
| 22ASF IV | 40 | | 24 | Atlas 3A3<br>1.0 | Alum<br>30.0 | 46.2 | 75.9 | 30.4 | 33.2 |
| 22BSF II | 40 | | 8 | Purifl.A-23<br>1.0 | Alum<br>30.0 | 71.6 | 96.3 | 37.2 | 60.9 |
| 22BSF III | 40 | | 16 | Purifl.A-23<br>1.0 | Alum<br>30.0 | 74.3 | 67.4 | 59.2 | - |
| 22BSF IV | 40 | | 24 | Purifl.A-23<br>1.0 | Alum<br>30.0 | 55.9 | - | 48.7 | - |
| 22CSF II | 40 | | 8 | Purifl.A-23<br>1.0 | Alum<br>30.0 | 86.7 | 96.7 | 56.9 | 77.8 |
| 22CSF III | 40 | | 16 | Purifl.A-23<br>1.0 | Alum<br>30.0 | 86.9 | 86.1 | 52.9 | 52.3 |
| 22CSF IV | 40 | | 24 | Purifl.A-23<br>1.0 | Alum<br>30.0 | 69.6 | 73.7 | 58.9 | 40.7 |
| 23SF II | 40 | | 8 | Atlas 4A4<br>1.0 | 0 | 97.6 | 97.0 | 82.7 | 75.8 |
| 23SF III | 40 | | 16 | Atlas 4A4<br>1.0 | 0 | 97.9 | 97.1 | 80.4 | 70.5 |
| 23SF IV | 40 | | 24 | Atlas 4A4<br>1.0 | 0 | 92.0 | 96.1 | 73.6 | 72.4 |
| 23ASF II | 40 | | 24 | Purifl.A-23<br>1.0 | 0 | 93.7 | 94.0 | 71.3 | 56.6 |
| 23ASF III | 40 | | 16 | Purifl.A-23<br>1.0 | 0 | 94.2 | 93.9 | 70.3 | 67.9 |
| 23ASF IV | 40 | | 8 | Purifl.A-23<br>1.0 | 0 | 93.5 | 94.0 | 48.1 | 53.4 |
| 23BSF II | 40 | | 24 | Mag.560C<br>1.0 | 0 | 81.8 | 79.2 | 57.9 | 65.9 |
| 23BSF III | 40 | | 8 | Mag.560C<br>1.0 | 0 | 98.3 | 79.2 | 63.7 | 78.7 |
| 23BSF IV | 40 | | 16 | Mag.560C<br>1.0 | 0 | 97.9 | 79.2 | 63.1 | 63.5 |

NOTE: RESULTS OF SCREEN PERFORMANCE WERE BASED ON 1970 TESTING DATA

# TABLE B-2

# COMBINED SEWER OVERFLOW FILTRATION TESTS

## SCREEN PERFORMANCE

(1970 TEST DATA)

| Run No. | Screen Size | Suspended Solids | | | Settleable Solids | | | B. O. D. | | | C. O. D. | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | Inf. Avg. (mg/l) | Eff. Avg. (mg/l) | % Removals | Inf. Avg. ml/l | Eff. Avg. ml/l | % Removals | Inf. Avg. (mg/l) | Eff. Avg. (mg/l) | % Removals | Inf. Avg. (mg/l) | Eff. Avg. (mg/l) | % Removals |
| 4SF | 20 Mesh | 470 | 390 | 17.0 | 10.2 | 4.8 | 52.9 | 169 | 160 | 5.3 | 483 | 300 | 37.9 |
| 5SF | 20 Mesh | — | — | - | — | — | - | — | — | - | — | — | - |
| 6SF | 20 Mesh | 219 | 173 | 21.0 | 5.4 | 2.3 | 57.4 | 72 | 56 | 22.2 | 175 | 146 | 16.6 |
| 7SF | 40Mesh | 265 | 210 | 20.8 | 4.4 | 2.1 | 52.3 | 49 | 43 | 12.3 | 154 | 142 | 7.8 |
| 9SF | 40 Mesh | 161 | 133 | 17.4 | 5.1 | 2.3 | 54.3 | 90 | 80 | 11.1 | 188 | 137 | 27.1 |
| 10SF | 40 Mesh | 155 | 93 | 40.0 | 3.2 | 1.6 | 50.0 | 61 | 57 | 6.6 | 240 | 190 | 20.8 |
| 11SF | 40 Mesh | 190 | 137 | 27.9 | 8.8 | 2.5 | 71.6 | 94 | 90 | 4.3 | 475 | 280 | 41.1 |
| 12SF | 40 Mesh | — | — | - | 7.6 | 3.5 | 53.9 | - | - | - | 455 | 374 | 17.8 |
| 13SF | 40 Mesh | 193 | 144 | 25.4 | 6.5 | 2.4 | 63.7 | 99 | 94 | 5.1 | 202 | 193 | 4.5 |
| 14SF | 40 Mesh | 94 | 74 | 21.3 | 3.4 | 0.9 | 73.5 | 59 | 52 | 11.9 | 165 | 146 | 11.5 |
| 14ASF | 40 Mesh | 48 | 36 | - | — | — | - | 67 | 60 | 11.7 | 172 | 134 | 22.1 |

# TABLE B-3 (SHEET No. 1)
# COMBINED SEWER OVERFLOW FILTRATION TESTS
# FILTER PERFORMANCE
(1970 TEST DATA)

| | | | | | | Suspended Solids | | | Settleable Solids | | | B.O.D. | | | C.O.D. | | | T.O.C. | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Run No. | Media | Flux Rate (gpm/ft$^2$) | Poly Feed (mg/l) | pH | Temp (°F) | Inf. Avg. (mg/l) | Eff. Avg. (mg/l) | % Removal | Inf. Avg. (mg/l) | Eff. Avg. (mg/l) | % Removal | Inf. Avg. (mg/l) | Eff. Avg. (mg/l) | % Removal | Inf. Avg. (mg/l) | Eff. Avg. (mg/l) | % Removal | Inf. Avg. | Eff. Avg. | % Removal |
| 4SF-II | 48" #4 Anth.<br>36" #612 Sand | 24 | 0 | 7.10 | 70 | 417 | 185 | 55.6 | 4.5 | 1.3 | 71.1 | 172 | 141 | 18.0 | 350 | 228 | 34.9 | - | - | - |
| 4SF-III | 48" #3 Anth.<br>36" #612 Sand | 24 | 0 | 7.13 | 70.0 | 390 | 187 | 52.1 | 4.5 | 1.7 | 62.2 | 167 | 130 | 22.2 | 350 | 210 | 40.0 | - | - | - |
| 5SF-I | 48" #4 Anth.<br>48" #612 Sand | 16 | 0 | 7.1 | 75.5 | 485 | 236 | 51.3 | 5.0 | 2.5 | 50.0 | 92 | 69 | 25.0 | 270 | 160 | 40.7 | - | - | - |
| 5SF-II | 48" #4 Anth.<br>36" #612 Sand | 16 | 0 | 7.0 | 75.5 | 470 | 140 | 70.2 | 5.0 | 1.5 | 70.0 | 85 | 60 | 29.4 | 240 | 136 | 43.3 | - | - | - |
| 5SF-III | 48" #3 Anth.<br>36" #612 Sand | 16 | 0 | 7.0 | 74.5 | 420 | 190 | 54.8 | 4.5 | 2.0 | 55.6 | 83 | 64 | 22.9 | 220 | 162 | 26.4 | - | - | - |
| 6SF-I | 48" #3 Anth.<br>36" #612 Sand | 24 | 0 | 6.85 | 72 | 173 | 63 | 63.6 | 2.6 | 0.7 | 73.1 | 63 | 49 | 22.2 | 140 | 120 | 14.3 | - | - | - |
| 6SF-III | 60" #3 Anth.<br>36" #612 Sand | 16 | 0 | 7.47 | 71.5 | 173 | 37 | 78.6 | 2.5 | 0.35 | 86.0 | 66 | 40 | 39.4 | 149 | 117 | 21.5 | - | - | - |
| 7SF-III | 60" #3 Anth.<br>36" #612 Sand | 16 | 0 | 7.08 | - | 205 | 48 | 76.6 | 2.5 | 0.7 | 72.0 | 53 | 45 | 15.1 | 118 | 82 | 30.5 | - | - | - |
| 8SF-I | 60" #3 Anth.<br>36" #612 Sand | 32 | 0 | 7.40 | - | 93 | 52 | 44.0 | 1.8 | 1.2 | 33.3 | 60 | 52 | 13.3 | 175 | 49 | 72.0 | - | - | - |
| 9SF-I | 48" #3 Anth.<br>36" #612 Sand | 24 | 0 | 7.20 | 64 | 114 | 74 | 35.1 | 2.0 | 1.1 | 45 | 77 | 67 | 13.0 | 117 | 83 | 29.1 | - | - | - |
| 9SF-II | 48" #3 Anth.<br>36" #612 Sand | 40 | 0 | 7.20 | 61.6 | 152 | 95 | 37.5 | 2.2 | 0.9 | 59.1 | 76 | 68 | 12.8 | 139 | 83 | 40.3 | - | - | - |
| 9SF-III | 60" #3 Anth.<br>36" #612 Sand | 10 | 0 | 7.20 | 64 | 114 | 31 | 72.8 | 2.0 | 0.07 | 96.5 | 77 | 49 | 36.4 | 117 | 44 | 62.4 | - | - | - |
| 9ASF-III | 60" #3 Anth.<br>36" #612 Sand | 40 | 0 | 7.0 | 67 | 91 | 75 | 17.6 | 1.9 | 0.4 | 78.9 | 95 | 71 | 25.3 | 190 | 110 | 42.1 | - | - | - |

# TABLE B-3 (SHEET No.2)

# COMBINED SEWER OVERFLOW FILTRATION TESTS

## FILTER PERFORMANCE

(1970 TEST DATA)

| Run No. | Media | Flux Rate (gpm/ft$^2$) | Poly Feed (ml/l) | Terminal Head Loss (Ft.) | Length of Run (Hr.) | Total Volume Filtered (Gal.) | Water | | | | Air | | Suspended Solids Mass Balance Analysis | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | | | | | Rate gpm/ft$^2$ | Length Min. | Tot. Vol. Gal. | % Total Water Filtered | Scfm Ft$^2$ | Length Min. | Filter Area (Ft.$^2$) | Total S.S. In Influent (Lbs) | Total S.S. In Effluent (Lbs) | Quantity Theoretically Removed in Column (lbs) | Susp. Sol. Removed in Backwash (lbs) |
| 4 SF-II | 48"#4 Anth.<br>36"#612 Sand | 24 | 0 | — | 1.0 | 306 | 70 | 11.4 | 170 | — | 14 | 3 | .213 | 1.068 | .047 | 1.021 | 1.6 |
| 4SF-III | 48"#3 Anth.<br>36"#612 Sand | 24 | 0 | 36.0 | 5.0 | 1,655 | 66 | 18.4 | 270 | 16 | 13.5 | 3.3 | .223 | 5.38 | 2.58 | 2.80 | — |
| 5SF-I | 48"#4 Anth.<br>48"#612 Sand | 16 | 0 | — | 1.5 | 1,440 | 50 | 9.3 | 455 | 31.5 | 12 | 4 | 1.00 | 5.83 | 2.83 | 3.00 | 9.5 |
| 5SF-II | 48"#4 Anth<br>36"#612 Sand | 16 | 0 | — | 3.5 | 714 | 69 | 15 | 224 | 31.3 | 14 | 3 | .213 | 2.79 | 0.83 | 1.96 | 1.82 |
| 5SF-III | 48"#3 Anth.<br>36"612 Sand | 16 | 0 | 22.0 | 8.2 | 1,812 | 62 | 19.5 | 267 | 14.7 | 18 | 3 | .223 | 6.35 | 2.79 | 3.56 | 3.2 |
| 6SF-I | 48"#3 Anth.<br>36"#612 Sand | 24 | 0 | 29.8 | 5.0 | 7,200 | 50 | 5.8 | 290 | 4.0 | 10.5 | 4 | 1.00 | 10.39 | 3.78 | 6.61 | 5.51 |
| 6SF-III | 60"#3 Anth.<br>36"#612 Sand | 16 | 0 | 16.1 | 11.0 | 2,431 | 75 | 11.3 | 189 | 7.3 | 13.5 | 4 | .223 | 3.50 | 0.75 | 2.75 | 1.81 |
| 7SF-III | 60"#3 Anth.<br>36"#612 Sand | 16 | 0 | 17.5 | 16.0 | 3,536 | 79 | 7 | 115 | 3.3 | 15 | 4 | .223 | 6.04 | 1.41 | 5.63 | 3.61 |
| 8SF-I | 60"#3 Anth.<br>36"#612 Sand | 32 | 0 | 16.5 | 10.0 | 4,410 | 75 | 5 | 85 | 1.9 | 15 | 3.5 | .223 | 3.42 | 1.94 | 1.48 | 1.28 |
| 9SF-I | 48"#3Anth.<br>36"#612 Sand | 24 | 0 | 34.0 | 10.0 | 14,400 | 50 | 4.5 | 225 | 1.6 | 12 | 5 | 1.00 | 18.21 | 8.86 | 9.33 | — |
| 9SF-II | 48"#3 Anth.<br>36"#612 Sand | 40 | 0 | 22.5 | 2.0 | 1,020 | 60 | 6.9 | 88 | 8.6 | 16.5 | 3.5 | .213 | 0.874 | 0.806 | .068 | — |
| 9SF-III | 60"#3 Anth.<br>36"#612 Sand | 10 | 0 | 9.0 | 10.0 | 1,380 | 71 | 4.6 | 74 | 5.4 | 18 | 4 | .223 | 1.31 | 0.35 | .96 | 1.7 |
| 9ASF-III | 60"#3Anth.<br>36"#612 Sand | 40 | 0 | 18.7 | 5.0 | 2,760 | 60 | 4.5 | 61 | 2.3 | 13.5 | 2.5 | .223 | 2.09 | 1.72 | .37 | — |

# TABLE B-3 (SHEET No.3)
# COMBINED SEWER OVERFLOW FILTRATION TESTS
## FILTER PERFORMANCE
(1970 TEST DATA)

| | | | | | | Suspended Solids | | | Settleable Solids | | | B. O. D. | | | C. O. D. | | | T. O. C. | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Run No. | Media | Flux Rate (gpm/ft²) | Poly Feed (mg/l) | pH | Temp (°F) | Inf. Avg. (mg/l) | Eff. Avg. (mg/l) | % Removal | Inf. Avg. (mg/l) | Eff. Avg. (mg/l) | % Removal | Inf. Avg. (mg/l) | Eff. Avg. (mg/l) | % Removal | Inf. Avg. (mg/l) | Eff. Avg. (mg/l) | % Removal | Inf. Avg. (mg/l) | Eff. Avg. (mg/l) | % Removal |
| 10SF-I | 48" #3 Anth.<br>36" #612 Sand | 32 | 0 | 6.7 | 65.5 | 132 | 80 | 39.4 | 1.7 | 0.51 | 70.0 | 93 | 86 | 7.5 | 244 | 187 | 23.4 | - | - | - |
| 10SF-II | 48" #3 Anth.<br>36" #612 Sand | 16 | 0 | 6.8 | 64.4 | 113 | 32 | 71.7 | 1.4 | 0.50 | 64.3 | 72.5 | 62 | 14.5 | 192 | 120 | 37.5 | - | - | - |
| 10SF-III | 60" #3 Anth.<br>36" #612 Sand | 24 | 0 | 6.8 | 64.6 | 113 | 53 | 53.1 | 1.5 | 0.38 | 74.7 | 72 | 51 | 29.2 | 192 | 126 | 34.4 | - | - | - |
| 10ASF-III | 60" #3 Anth.<br>36" #612 Sand | 24 | .5 | 7.15 | 65.7 | 148 | 46 | 68.9 | 2.15 | 0.62 | 71.2 | 66 | 63 | 4.5 | 151 | 88 | 41.7 | - | - | - |
| 11SF-I | 48" #3 Anth.<br>36" #612 Sand | 32 | .5 | 7.1 | 66.1 | 175 | 115 | 34.3 | 3.3 | 1.5 | 54.5 | 100 | 68 | 32.0 | 287 | 230 | 19.9 | 135.7 | 78 | 42.5 |
| 11SF-II | 48" #3 Anth.<br>36" #612 Sand | 16 | 2.0 | 7.2 | 66.2 | 149 | 66 | 55.7 | 2.9 | 0.65 | 77.6 | 100 | 67 | 33.0 | 287 | 200 | 30.3 | 133 | 71 | 46.6 |
| 11SF-III | 60" #3 Anth.<br>36" #612 Sand | 24 | 2.0 | 7.2 | 66.2 | 149 | 69 | 53.7 | 2.9 | 0.08 | 97.2 | 100 | 70 | 30.0 | 287 | 207 | 27.9 | 133 | 92.2 | 30.7 |
| 13SF-II | 48" #3 Anth.<br>36" #612 | 24 | 1.5 | 7.07 | 62.0 | 144 | 69 | 52.1 | 2.4 | 0.65 | 72.9 | 94 | 75 | 20.2 | 193 | 114 | 40.9 | 67.0 | 40.7 | 39.3 |
| 13SF-III | 48" #3 Anth.<br>36" #612 Sand | 16 | 1.5 | 7.07 | - | 144 | 49 | 66.0 | 2.4 | 0.28 | 88.3 | 94 | 67 | 28.7 | 193 | 98 | 49.2 | 67.0 | 31.1 | 53.6 |
| 13SF-IV | 48" #3 Anth.<br>36" #612 Sand | 10 | 1.5 | 7.07 | 62.0 | 144 | 40 | 72.2 | 2.4 | 0.3 | 87.5 | 94 | 66 | 29.8 | 193 | 92 | 52.3 | 67.0 | 25.0 | 62.7 |
| 14SF-I | 48" #3 Anth.<br>36" #612 Sand | 16 | .5 | 7.0 | 56.6 | 85 | 39 | 54.0 | 1.4 | 0.31 | 77.9 | 64 | 50 | 21.9 | 133 | 95 | 28.6 | 50.0 | 33 | 34.0 |
| 14ASF-I | 48" #3 Anth.<br>36" #612 Sand | 32 | .5 | 7.25 | 58 | 60 | 25 | 58.3 | 0.72 | 0.13 | 81.9 | 61 | 46 | 24.6 | 134 | 127 | 5.2 | 46.0 | 37 | 19.6 |

# TABLE B-3 (SHEET No.4)

## COMBINED SEWER OVERFLOW FILTRATION TESTS

## FILTER PERFORMANCE

(1970 TEST DATA)

| | | | | | | | Water | | | | Air | | Suspended Solids Mass Balance Analysis | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Run No. | Media | Flux Rate (gpm/ft$^2$) | Poly Feed (ml/l) | Terminal Head Loss (Ft.) | Length of Run (Hr.) | Total Volume Filtered (Gal.) | Rate gpm/ft$^2$ | Length Min. | Tot. Vol. Gal. | % Total Water Filtered | Scfm Ft$^2$ | Length Min. | Filter Area (Ft.$^2$) | Total S.S. in Influent (Lbs) | Total S.S. In Effluent (Lbs) | Quantity Theoretically Removed in Column (lbs) | Susp. Sol. Removed in Backwash (lbs) |
| 10SF-I | 48"Ø3 Anth.<br>36"Ø612 Sand | 32 | 0 | 14.8 | 3.0 | 5,760 | 49 | 10 | 490 | 8.5 | 10 | 4 | 1.00 | 6.33 | 3.84 | 2.49 | — |
| 10SF-II | 48"Ø3 Anth.<br>36"Ø612 Sand | 16 | 0 | 12.5 | 10.5 | 2,142 | 60 | 9.6 | 122 | 5.7 | 15.5 | 4 | .213 | 2.02 | 0.57 | 1.45 | 1.86 |
| 10SF-III | 60"Ø3 Anth.<br>36"Ø612 Sand | 24 | 0 | 11.2 | 10.5 | 3,475 | 71 | 4 | 64 | 1.8 | 12 | 3 | .223 | 3.27 | 1.53 | 1.74 | .51 |
| 10ASF-III | 60"Ø3 Anth.<br>36"Ø612 Sand | 24 | .5 | 16.8 | 10.0 | 3,310 | — | — | — | — | — | — | .213 | 4.02 | 1.27 | 2.75 | — |
| 11SF-I | 48"Ø3 Anth.<br>36"Ø612 Sand | 32 | .5 | 13.8 | 3.5 | 6,720 | 66 | 10.7 | 711 | 10.6 | 6.8 | 10 | 1.00 | 9.80 | 6.45 | 3.35 | — |
| 11SF-II | 48"Ø3 Anth.<br>36"Ø612 Sand | 16 | 2.0 | 8.0 | 10.0 | 2,040 | 90 | 2.5 | 47 | 2.3 | 2.4 | 6 | .213 | 2.53 | 1.12 | 1.41 | 2.05 |
| 11SF-III | 60"Ø3 Anth.<br>36"Ø612 Sand | 24 | 3.0 | 25.0 | 10.0 | 3,210 | 52 | 4 | 47 | 1.4 | 2.1 | 3 | .223 | 4.0 | 1.90 | 2.11 | .695 |
| 13SF-II | 48"Ø3 Anth.<br>36"Ø612 Sand | 24 | 1.5 | 16.0 | 10.5 | 3,213 | 70 | 25 | 371 | 4.2 | 4.0 | 3 | .213 | 3.85 | 1.85 | 2.00 | 8.0 |
| 13SF-III | 48"Ø3 Anth.<br>36"Ø612 Sand | 16 | 1.5 | 4.7 | 10.5 | 2,320 | 31 | 14 | 95 | 4.1 | 4.1 | 29 | .223 | 2.78 | .95 | 1.83 | 1.19 |
| 13SF-IV | 48"Ø3 Anth.<br>36"Ø612 Sand | 10 | 1.5 | 5.2 | 10.5 | 1,335 | 32 | 13.5 | 91 | 6.8 | 4.0 | 9 | .213 | 1.60 | .44 | 1.16 | .36 |
| 14SF-I | 48"Ø3 Anth.<br>36"Ø612 Sand | 16 | .5 | 2.3 | 6.0 | 5,760 | — | — | — | — | — | — | 1.00 | 4.08 | 1.87 | 2.21 | — |
| 14ASF-I | 48"Ø3 Anth.<br>36"Ø612 Sand | 32 | .5 | 22.3 | 8.0 | 15,560 | — | — | — | — | — | — | 1.00 | 7.66 | 3.20 | 4.46 | — |

# TABLE B-3 (SHEET No.5)
# COMBINED SEWER OVERFLOW FILTRATION TESTS
# FILTER PERFORMANCE
(1971 TEST DATA)

| Run No. | Flux Rate (gpm/ft²) | Coagulant Feed (mg/l) | Polymer Feed (mg/l) | pH | Temp. (°F) | Suspended Solids | | | Settleable Solids | | | BOD | | | COD | | | Total Phosphorus | | | Length of Run (Hours) | Total Head Loss (ft.) |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | | | | Inf. Avg. (mg/l) | Eff. Avg. (mg/l) | % Removal | Inf. Avg. (mg/l) | Eff. Avg. (mg/l) | % Removal | Inf. Avg. (mg/l) | Eff. Avg. (mg/l) | % Removal | Inf. Avg. (mg/l) | Eff. Avg. (mg/l) | % Removal | Inf. Avg. (mg/l) | Eff. Avg. (mg/l) | % Removal | | |
| 17SFII | 10 | 0 | 0 | - | 53 | 223.9 | 66 | 70.5 | 2.3 | .2 | 91.3 | 279.2 | 275.8 | 1.2 | 265 | 165.3 | 37.6 | -- | -- | -- | 6.0 | 4.2 |
| 17SFIII | 16 | 0 | 0 | - | 53 | 209.5 | 74.8 | 64.3 | 2.3 | .3 | 87.0 | 259.2 | 232.5 | 10.3 | 265 | 149 | 43.8 | -- | -- | -- | 6.0 | 6.2 |
| 17SFIV | 24 | 0 | 0 | - | 53 | 214.8 | 106.8 | 50.3 | 2.4 | .3 | 87.5 | 257.5 | 185.0 | 28.2 | 301 | 196.8 | 34.6 | -- | -- | -- | 4.0 | 28.8 |
| 18SFII | 8 | 0 | Atlas 4A4<br>1.0 | 6.8 | 62 | 362.3 | 153.3 | 57.5 | 3.3 | .2 | 93.9 | 173.2 | 112.3 | 35.2 | 488.3 | 412.5 | 15.5 | -- | -- | -- | 5.5 | 4.6 |
| 18SFIII | 24 | 0 | Atlas 4A4<br>1.0 | 6.8 | 62 | 362.3 | 292.4 | 19.3 | 3.3 | 1.2 | 63.6 | 173.2 | 119.8 | 30.8 | 486.3 | 373.8 | 23.4 | -- | -- | -- | 5.5 | 10.9 |
| 18SFIV | 16 | 0 | Atlas 4A4<br>1.0 | 6.8 | 62 | 362.5 | 256.7 | 29.1 | 3.1 | 1.1 | 64.5 | 154.8 | 142.7 | 7.8 | -- | -- | -- | -- | -- | -- | 5.5 | 8.7 |
| 19SFIII | 8 | Alum<br>30.0 | Mag. 560C<br>1.0 | 6.7 | 68 | 301.7 | 108.0 | 64.2 | 3.8 | .2 | 94.7 | 425 | 360 | 15.3 | 138.5 | 83.0 | 40.1 | .61 | .16 | 73.8 | 5.5 | 10.3 |
| 19SFIV | 16 | Alum<br>30.0 | Mag. 560C<br>1.0 | 6.7 | 68 | 324.5 | 181.0 | 44.2 | 3.8 | 0.8 | 78.9 | 457.5 | 390 | 14.8 | -- | -- | -- | .57 | .37 | 35.0 | 5.5 | 23.1 |
| 19ASFII | 24 | Alum<br>30.0 | Mag. 560C<br>1.0 | 6.8 | 69 | 192.0 | 48.0 | 75.0 | 2.0 | 0.3 | 85.0 | 37 | 28 | 24.3 | 141 | 72.7 | 48.4 | .51 | .19 | 62.7 | 3.0 | 31.4 |
| 19ASFIV | 32 | Alum<br>30.0 | Mag. 560C<br>1.0 | 6.8 | 69 | 192.0 | 90.0 | 53.1 | 2.0 | .4 | 80.0 | 37 | 25 | 32.4 | 141 | 62.7 | 55.5 | .51 | .20 | 60.8 | 3.0 | 39.3 |
| 19BSFII | 16 | Alum<br>30.0 | | 7.2 | 70 | 278 | 176.3 | 36.6 | 2.5 | 2.4 | 4.0 | 43.7 | 35.8 | 18.1 | 173.8 | 152.2 | 12.4 | .50 | .31 | 38.0 | 6.0 | 17.5 |
| 19BSFIV | 16 | Alum | Mag. 560C | 7.3 | 70 | 221 | 125.3 | 43.3 | 2.5 | 1.4 | 44.0 | 44.8 | 30.7 | 31.5 | 177.8 | 93.7 | 47.3 | .50 | .21 | 58.0 | 6.0 | 12.9 |

**Media**

60" No. 3 Anth.
36" No. 612 Sand

# TABLE B-3 (SHEET No.6)

# COMBINED SEWER OVERFLOW FILTRATION TESTS

# FILTER PERFORMANCE

(1971 TEST DATA)

| Run No. | Flux Rate (gpm/ft²) | Coagulant Feed (mg/l) | Polymer Feed (mg/l) | pH | Temp. (°F) | Suspended Solids | | | Settleable Solids | | | BOD | | | COD | | | Total Phosphorus | | | Length of Run (Hours) | Total Head Loss (ft.) |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | | | | Inf. Avg. (mg/l) | Eff. Avg. (mg/l) | % Removal | Inf. Avg. (mg/l) | Eff. Avg. (mg/l) | % Removal | Inf. Avg. (mg/l) | Eff. Avg. (mg/l) | % Removal | Inf. Avg. (mg/l) | Eff. Avg. (mg/l) | % Removal | Inf. Avg. (mg/l) | Eff. Avg. (mg/l) | % Removal | | |
| 19CSFII | 16 | Alum 30.0 | Herc 836 1.0 | 7.2 | 70 | 237.7 | 125.7 | 47.1 | 2.6 | 1.5 | 42.3 | 46.0 | 36.0 | 21.7 | 139.0 | 99.7 | 28.3 | .60 | .20 | 66.7 | 6.0 | 17.2 |
| 19CSFIV | 16 | Alum 30.0 | Herc 836 1.0 | 6.9 | 70 | 286.0 | 102.3 | 64.2 | 2.5 | 1.3 | 48.0 | 47.3 | 45.0 | 48.6 | 141.8 | 113.0 | 20.3 | .61 | .23 | 62.3 | 6.0 | 8.1 |
| 20SFII | 24 | FeCl₃ 25.0 | Atlas 4A4 1.0 | 7.1 | 69 | 90.0 | 49.0 | 45.6 | 0.67 | 0.1 | 85.1 | - | - | - | - | - | - | .30 | .16 | 46.7 | 3.0 | 20.1 |
| 20SFIII | 16 | FeCl₃ 25.0 | Atlas 4A4 1.0 | 7.1 | 69 | 90.0 | 19.7 | 78.1 | 0.67 | 0.1 | 85.1 | 67.3 | 47.0 | 30.2 | 136.7 | 93.8 | 31.4 | .30 | .10 | 66.7 | 7.0 | 33.3 |
| 20SFIV | 8 | FeCl₃ 25.0 | Atlas 4A4 1.0 | 7.0 | 69 | 91.5 | 9.6 | 89.5 | 0.67 | 0.1 | 85.1 | 67.3 | 43.4 | 35.5 | 136.7 | 90.2 | 34.0 | .30 | .11 | 63.3 | 5.0 | 28.1 |
| 20ASFII | 16 | Alum 30.0 | Atlas 4A4 1.0 | 7.1 | 75 | 179.6 | 68.5 | 61.9 | 1.2 | 0.3 | 75.0 | 73.2 | 48.3 | 34.0 | 165.4 | 104.0 | 9.8 | .36 | .11 | 69.4 | 4.0 | 8.1 |
| 20ASFIII | 16 | Alum 30.0 | Atlas 4A4 1.0 | 7.1 | 75 | 179.6 | 81.5 | 54.6 | 1.2 | .4 | 66.7 | 73.2 | 49.0 | 33.1 | 165.4 | 104.8 | 36.6 | .36 | .18 | 50.0 | 3.0 | 21.7 |
| 21SFIII | 8 | Alum 30.0 | Swift x-400 1.0 | 7.2 | 69 | 128.0 | 54.3 | 57.6 | .45 | .05 | 88.9 | 38.8 | 19.5 | 49.7 | 69.5 | 32.0 | 54.0 | .18 | .06 | 66.7 | 6.0 | 1.76 |
| 21SFIV | 16 | Alum 30.0 | Swift x-400 1.0 | 7.2 | 69 | 145.0 | 107.3 | 32.9 | -- | -- | - | 38.8 | 31.0 | 20.1 | - | - | - | .16 | .08 | 50.0 | 6.0 | 4.04 |
| 21ASFII | 8 | Alum 50.0 | Swift x-400 1.0 | 7.2 | 73 | 54.0 | 31.2 | 42.2 | -- | -- | - | 42.8 | 22.8 | 46.7 | 72.4 | 45.8 | 36.7 | .26 | .13 | 50.0 | 6.0 | 1.91 |
| 21ASFIII | 24 | Alum 30.0 | Swift x-400 1.0 | 7.2 | 73 | 54.0 | 32.0 | 40.7 | .42 | .05 | 88.1 | 42.8 | 19.8 | 53.7 | 72.4 | 40.8 | 77.5 | .26 | .12 | 53.8 | 6.0 | 8.36 |
| 22SFII | 8 | Alum 30.0 | Swift x-400 1.0 | 7.5 | 69 | 322.7 | 74.7 | 76.9 | 2:42 | .05 | 97.9 | 100.0 | 38.3 | 61.7 | 240.7 | 133.7 | 46.2 | 1.0 | .38 | 62.0 | 4.0 | 2.6 |

Media

60" No. 3 Anth.
16" No. 612 Sand

# TABLE B-3 (SHEET No.7)

# COMBINED SEWER OVERFLOW FILTRATION TESTS

## FILTER PERFORMANCE

(1971 TEST DATA)

| | | | | | | Suspended Solids | | | Settleable Solids | | | BOD | | | COD | | | Total Phosphorus | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Run No. | Flux Rate (gpm/ft²) | Coagulant Feed (mg/l) | Polymer Feed (mg/l) | pH | Temp (°F) | Inf. Avg. (mg/l) | Eff. Avg. (mg/l) | % Removal | Inf. Avg. (mg/l) | Eff. Avg. (mg/l) | % Removal | Inf. Avg. (mg/l) | Eff. Avg. (mg/l) | % Removal | Inf. Avg. (mg/l) | Eff. Avg. (mg/l) | % Removal | Inf. Avg. (mg/l) | Eff. Avg. (mg/l) | % Removal | Length of Run (Hours) | Total Head Loss (ft.) |
| 22SFIII | 16 | Alum 30.0 | Swift x-400 1.0 | 7.5 | 69 | 322.7 | 71.7 | 77.8 | 2.4 | .5 | 79.2 | 100.0 | 40.8 | 59.2 | 248.7 | 116.0 | 53.4 | 1.0 | .51 | 49.0 | 6.0 | 22.2 |
| 22SFIV | 24 | Alum 30.0 | Swift x-400 1.0 | 7.5 | 69 | 322.7 | 77.0 | 76.1 | 2.4 | .9 | 62.5 | 100.0 | 40.5 | 59.5 | 248.7 | 124.8 | 49.8 | 1.0 | .59 | 41.0 | 3.0 | 14.2 |
| 22ASFII | 8 | Alum 30.0 | Atlas 3A3 1.0 | 7.2 | 60 | 251.0 | 57.3 | 77.1 | 1.9 | .2 | 84.2 | 43.7 | 26.2 | 40.4 | - | - | - | .82 | .50 | 39.0 | 6.0 | 2.14 |
| 22ASFIII | 16 | Alum 30.0 | Atlas 3A3 1.0 | 7.2 | 60 | 251.0 | 128.0 | 49.0 | 1.9 | .8 | 57.8 | 43.7 | 23.8 | 45.5 | - | - | - | .82 | .58 | 29.3 | 6.0 | 5.1 |
| 22ASFIV | 24 | Alum 30.0 | Atlas 3A3 1.0 | 7.2 | 60 | 251.0 | 177.5 | 29.3 | 1.9 | 1.1 | 42.1 | 43.7 | 33.8 | 22.7 | 102.8 | 89.3 | 13.3 | .82 | .52 | 36.6 | 6.0 | 13.5 |
| 22BSFII | 8 | Alum 30.0 | Purifl. A-23 1.0 | 6.6 | 51 | 159.7 | 59.7 | 62.6 | 2.3 | .2 | 91.3 | 43.0 | 30.0 | 30.2 | 168.8 | 85.5 | 49.3 | .90 | .24 | 73.3 | 6.0 | 4.2 |
| 22BSFIII | 16 | Alum 30.0 | Purifl. A-23 1.0 | 6.6 | 51 | 159.7 | 54.0 | 66.2 | 2.3 | 1.8 | 21.7 | 43.0 | 19.5 | 54.7 | - | - | - | .90 | .47 | 47.8 | 3.0 | 2.7 |
| 22BSFIV | 24 | Alum 30.0 | Purifl. A-23 1.0 | 6.6 | 51 | 159.7 | 92.5 | 42.1 | - | - | - | 43.0 | 24.5 | 43.0 | - | - | - | .90 | .52 | 42.2 | 5.0 | 17.1 |
| 22CSFII | 8 | Alum 30.0 | Purifl. C-31 1.0 | [illegible] | 50 | 217.5 | 38.0 | 82.5 | 1.9 | .15 | 92.2 | 65.8 | 31.5 | 52.1 | 163.8 | 47.0 | 71.3 | .68 | .14 | 79.4 | 4.0 | 2.8 |
| 22CSFIII | 16 | Alum 30.0 | Purifl. C-31 1.0 | 6.5 | 50 | 217.5 | 65.3 | 70.0 | 1.9 | .63 | 66.8 | 66.8 | 34.5 | 47.6 | 163.8 | 101.5 | 38.0 | .68 | .29 | 57.4 | 4.0 | 5.4 |
| 22CSFIV | 24 | Alum 30.0 | Purifl. C-31 1.0 | 6.5 | 50 | 222.5 | 89.0 | 60.0 | 1.9 | 1.2 | 36.8 | 65.8 | 30.0 | 54.4 | 163.8 | 126.3 | 22.9 | .68 | .50 | 23.5 | 4.0 | 9.2 |
| 23SFII | 8 | 0 | Atlas 4A4 1.0 | 7.1 | 49 | 300.7 | 10.0 | 96.7 | 1.4 | <0.1 | 92.8 | 66.3 | 12.7 | 80.8 | 189.2 | 59.5 | 68.6 | - | - | - | 5.0 | 12.0 |

**Media**

60" No. 3 Anth.
36" No. 612 Sand

# TABLE B-3 (SHEET No.8)

# COMBINED SEWER OVERFLOW FILTRATION TESTS

# FILTER PERFORMANCE

(1971 TEST DATA)

| | | | | | | Suspended Solids | | | Settleable Solids | | | BOD | | | COD | | | Total Phosphorus | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Run No. | Flux Rate (gpm/ft²) | Coagulant Feed (mg/l) | Polymer Feed (mg/l) | pH | Temp. (°F) | Inf. Avg. (mg/l) | Eff. Avg. (mg/l) | % Removal | Inf. Avg. (mg/l) | Eff. Avg. (mg/l) | % Removal | Inf. Avg. (mg/l) | Eff. Avg (mg/l) | % Removal | Inf. Avg. (mg/l) | Eff. Avg. (mg/l) | % Removal | Inf. Avg. (mg/l) | Eff. Avg. (mg/l) | % Removal | Length of Run (Hours) | Total Head Loss (ft.) |
| 23SFIII | 16 | 0 | Atlas 4A4<br>1.0 | 7.1 | 49 | 300.7 | 9.0 | 97.0 | 1.4 | <0.1 | 92.9 | 66.3 | 14.5 | 78.1 | 189.2 | 72.5 | 61.7 | - | - | - | 5.0 | 19.9 |
| 23SFIV | 24 | 0 | Atlas 4A4<br>1.0 | 7.1 | 49 | 300.7 | 28.0 | 90.7 | 1.4 | .13 | 90.7 | 66.3 | 18.0 | 72.9 | 189.2 | 67.8 | 64.2 | - | - | - | 5.0 | 40.9 |
| 23ASFII | 24 | 0 | Purifl. A23<br>1.0 | 7.5 | 50 | 210.7 | 17.7 | 91.6 | .7 | <0.1 | 85.7 | 44.8 | 14.3 | 68.1 | 156.2 | 48.7 | 68.8 | .71 | .40 | 43.7 | 4.0 | 12.3 |
| 23ASFIII | 16 | 3 | Purifl. A23<br>1.0 | 7.5 | 50 | 210.7 | 16.3 | 92.3 | .7 | <0.1 | 85.7 | 44.8 | 14.8 | 67.0 | 156.2 | 65.2 | 58.3 | .71 | .39 | 45.1 | 6.0 | 9.7 |
| 23ASFIV | 8 | 0 | Purifl. A23<br>1.0 | 7.5 | 50 | 210.7 | 18.0 | 91.5 | .7 | <0.1 | 85.7 | 44.8 | 25.8 | 42.4 | 156.2 | 60.5 | 61.3 | .71 | .43 | 39.4 | 6.0 | 5.3 |
| 23BSFII | 24 | 0 | Mag. 560C<br>1.0 | 6.9 | 50 | 392.8 | 94.0 | 76.1 | 2.0 | 1.0 | 50.0 | 67.0 | 31.3 | 53.3 | 161.2 | 70.5 | 55.6 | .76 | .55 | 26.3 | 3.0 | 26.7 |
| 23BSFIII | 8 | 0 | Mag. 560C<br>1.0 | 6.9 | 50 | 392.8 | 8.9 | 97.7 | 2.0 | <0.1 | 50.0 | 67.0 | 27.0 | 59.7 | 161.2 | 44.5 | 72.4 | .76 | .40 | 47.2 | 6.0 | 6.6 |
| 23BSFIV | 16 | 0 | Mag. 560C<br>1.0 | 6.9 | 50 | 392.8 | 7.0 | 98.2 | 2.0 | 0.1 | 50.0 | 67.0 | 27.5 | 59.0 | 161.2 | 73.5 | 54.4 | .76 | .36 | 52.6 | 4.0 | 12.3 |

Media

60" No. 3 Anth.
36" No. 612 Sand

# TABLE B-4

# COMBINED SEWER OVERFLOW FILTRATION TESTS

# COLIFORM REDUCTION BY FILTRATION

(1970 TEST DATA)

| | | | | Fecal Coliform | | | Total Coliform | | |
|---|---|---|---|---|---|---|---|---|---|
| Run No. | Media | Flux Rate | Poly Feed | Inf. Avg. (No. x10⁶ / 100ml) | Eff. Avg. (No. x10⁶ / 100ml) | % Removal | Inf. Avg. (x10⁶ / 100ml) | Eff. Avg. (x10⁶ / 100ml) | % Removal |
| 4SF-II | 48"#4Anth.<br>36"#612Sand | 24 | 0 | 1.6 | 1.2 | 25 | — | — | — |
| 4SF-III | 48"#3 Anth.<br>36"#612 Sand | 24 | 0 | 1.3 | 1.2 | 7.6 | — | — | — |
| 5SF-I | 48"#4 Anth.<br>48"#612 Sand | 16 | 0 | .93 | .7 | 24.8 | 33.0 | — | — |
| 5SF-II | 48"#4 Anth.<br>36"#612 Sand | 16 | 0 | .85 | .8 | 5.8 | 33.0 | 11.0 | 66.6 |
| 5SF-III | 48"#3 Anth.<br>36"#612 Sand | 16 | 0 | .74 | .4 | 46.0 | 33.0 | — | — |
| 6SF-I | 48"#3 Anth.<br>36"#612 Sand | 24 | 0 | 1.8 | .8 | 55.5 | 1.9 | — | — |
| 6SF-III | 60"#3 Anth.<br>36"#612 Sand | 16 | 0 | 1.7 | 1.0 | 41.3 | 1.9 | — | — |
| 7SF-III | 60"#3 Anth.<br>36"#612 Sand | 16 | 0 | 3.1 | — | — | 7.0 | 15.0 | 0 |
| 8SF-III | 60"#3 Anth.<br>36"#612 Sand | 32 | 0 | 1.0 | .8 | 20.0 | 7.6 | 2.8 | 63.2 |
| 9SF-I | 48"#3 Anth.<br>36"#612 Sand | 24 | 0 | 15.2 | 13.7 | 9.8 | 29.5 | 11.4 | 61.4 |
| 9SF-II | 48"#3 Anth.<br>36"#612 Sand | 40 | 0 | — | 4.6 | — | 29.5 | 10.0 | 66.1 |
| 9SF-III | 60"#3 Anth.<br>36"#612 Sand | 10 | 0 | 15.2 | 2.7 | 82.2 | 29.5 | 4.0 | 86.4 |
| 9ASF-III | 60"#3 Anth.<br>36"#612 Sand | 40 | 0 | 3.2 | 2.8 | 12.5 | 52.5 | 26.7 | 49.2 |
| 10SF-I | 48"#3 Anth.<br>36"#612 Sand | 32 | 0 | 5.1 | 4.8 | 11.0 | 16.0 | 22.0 | 0 |
| 10SF-II | 48"#3 Anth.<br>36"#612 Sand | 16 | 0 | 4.6 | 2.8 | 39.2 | 16.0 | 25.3 | 0 |
| 10SF-III | 60"#3 Anth.<br>36"#612 Sand | 24 | 0 | 4.6 | 2.1 | 54.4 | 16.0 | 19.2 | 0 |
| 10ASF-III | 60"#3 Anth.<br>36"#612 Sand | 24 | 0.5 | 1.8 | 1.0 | 44.4 | 5.6 | 3.9 | 30.3 |
| 11SF-I | 48"#3 Anth.<br>36"#612 Sand | 32 | 0.5 | 11.0 | 10 | 9.2 | 79.7 | 51.5 | 35.3 |
| 11SF-II | 48"#3 Anth.<br>36"#612 Sand | 16 | 2.0 | 11.0 | 8.3 | 24.6 | 79.7 | 41.0 | 48.5 |
| 11SF-III | 60"#3 Anth.<br>36"#612 Sand | 24 | 2.0 | 11.0 | 7.8 | 29.1 | 79.7 | 47.0 | 40.4 |
| 13SF-II | 48"#3 Anth.<br>36"#612 Sand | 24 | 1.5 | 4.1 | 2.8 | 31.7 | 24.3 | 6.8 | 72.0 |
| 13SF-III | 48"#3 Anth.<br>36"#612 Sand | 16 | 1.5 | 4.1 | 2.7 | 34.2 | 24.3 | 8.2 | 66.2 |
| 13SF-IV | 48"#3 Anth.<br>36"# 612 Sand | 10 | 1.5 | 4.1 | 2.8 | 31.7 | 15.0 | 1.0 | 93.4 |
| 14SF-I | 48"#3 Anth.<br>36"#612 Sand | 16 | 0.5 | 3.5 | 2.3 | 34.2 | 21.0 | 16.3 | 22.4 |
| 14ASF-I | 48"#3 Anth.<br>36"#612 Sand | 32 | 0.5 | 3.3 | 2.0 | 39.4 | 15.3 | 5.5 | 64.1 |

# TABLE B-5 (SHEET No. 1)
# COMBINED SEWER OVERFLOW FILTRATION TESTS
# SOLIDS REDUCTION BY FILTRATION

(1970 TEST DATA)

| | | | | Turbidity | | Total Solids | | | | | | Total Volatile Solids | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | | | | Grab | | | Composite | | | Grab | | | Composite | | |
| Run No. | Media | Flow Flux (gpm/ft²) | Poly Feed mg/l | Inf. Avg. JTU | Eff. Avg. JTU | Inf. Avg. | Eff. Avg. | % Removal | Inf. | Eff. | % Removal | Inf. | Eff. | % Removal | Inf. Avg. | Eff. Avg. | % Removal |
| 4SF-II | 48"#4Anth.<br>36"#612 Sand | 24 | 0 | 397 | 235 | 682 | 505 | 26.0 | — | — | — | — | — | — | — | — | — |
| 4SF-III | 48"#3Anth.<br>36"#612 Sand | 24 | 0 | 413 | 240 | 685 | 511 | 25.3 | 654 | 482 | 26.2 | — | — | — | — | — | — |
| 5SF-I | 48"# 4Anth.<br>36"#612 Sand | 16 | 0 | 457 | 227 | 876 | 566 | 35.5 | — | — | — | — | — | — | — | — | — |
| 5SF-II | 48"#4Anth.<br>36"#612 Sand | 16 | 0 | 352 | 192 | 826 | 426 | 48.4 | — | — | — | — | — | — | — | — | — |
| 5SF-III | 48"#3Anth.<br>36"#612Sand | 16 | 0 | 320 | 194 | 726 | 476 | 34.4 | — | — | — | — | — | — | — | — | — |
| 6SF-I | 48"#3Anth.<br>36"#612 Sand | 24 | 0 | 140 | 87 | 470 | 368 | 27.1 | 380 | 310 | 18.4 | — | — | — | — | — | — |
| 6SF-III | 60"#3Anth.<br>36"#612 Sand | 16 | 0 | 178 | 87 | 485 | 338 | 30.3 | 380 | 264 | 30.6 | — | — | — | — | — | — |
| 7SF-III | 60"#3Anth.<br>36"#612 Sand | 16 | 0 | 179 | 68 | 574 | 406 | 29.3 | 526 | 396 | 24.7 | — | — | — | — | — | — |
| 8SF-III | 60"#3Anth.<br>36"#612Sand | 32 | 0 | 122 | 111 | 382 | 393 | 0 | — | — | — | — | — | — | — | — | — |
| 9SF-I | 48"#3Anth.<br>36"#612 Sand | 24 | 0 | 660 | 98 | 421 | 417 | 1.3 | 422 | 369 | 12.6 | — | — | — | — | — | — |
| 9SF-II | 48"#3Anth.<br>36"#612 Sand | 40 | 0 | 153 | 113 | 422 | 380 | 10.0 | — | — | — | — | — | — | — | — | — |
| 9SF-III | 60"#3Anth.<br>36"#612Sand | 10 | 0 | 660 | 47 | 421 | 349 | 17.0 | 422 | 312 | 26.0 | — | — | — | — | — | — |
| 9ASF-III | 60"#3Anth.<br>36"#612 Sand | 40 | 0 | 125 | 81 | 519 | 470 | 9.5 | — | — | — | — | — | — | — | — | — |
| 10SF-I | 48"#3Anth.<br>36"#612 Sand | 32 | 0 | 201 | 125 | 433 | 324 | 26.2 | 356 | — | — | — | — | — | — | — | — |
| 10SF-II | 48"#3Anth<br>36"#612 Sand | 16 | 0 | 178 | 122 | 368 | 279 | 24.2 | 356 | 288 | 19.0 | — | — | — | — | — | — |
| 10SF-III | 60"#3Anth.<br>36"#612 Sand | 24 | 0 | 178 | 117 | 368 | 299 | 18.8 | 356 | 292 | 18.0 | — | — | — | — | — | — |
| 10ASF-III | 60"#3Anth.<br>36"#612 Sand | 24 | .5 | 126 | 73 | 424 | 352 | 17.0 | — | — | — | — | — | — | — | — | — |

# TABLE B-5 (SHEET No.2)

# COMBINED SEWER OVERFLOW FILTRATION TESTS

# SOLIDS REDUCTION BY FILTRATION

(1970 TEST DATA)

| | | | | Turbidity | | Total Solids | | | | | | Total Volatile Solids | | | | | | Total Nonvolatile Solids | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | | | | Grab | | | Composite | | | Grab | | | Composite | | | Grab | | | Composite | | |
| Run No. | Media | Flow Flux (gpm/ft²) | Poly Feed mg/l | Inf. Avg. JTU | Eff. Avg. JTU | Inf. Avg. | Eff. Avg. | % Removal | Inf. | Eff. | % Removal | Inf. | Eff. | % Removal | Inf. Avg. | Eff. Avg. | % Removal | Inf. Avg. | Eff. Avg. | % Removal | Inf. | Eff. | % Removal |
| 12SF-I | 48"#3Anth.<br>36"#612 Sand | 32 | .5 | 178 | 135 | 582 | 532 | 8.6 | — | 512 | — | — | — | — | — | — | — | — | — | — | — | — | — |
| 12SF-II | 48"#3Anth.<br>36"#612 Sand | 18 | 0 | 170 | 106 | 565 | 447 | 20.8 | 478 | 468 | 2.1 | — | — | — | — | — | — | — | — | — | — | — | — |
| 12SF-III | 60"#3Anth.<br>36"#612 Sand | 24 | 2.0 | 170 | 111 | 565 | 509 | 9.9 | 478 | 453 | 5.2 | — | — | — | — | — | — | — | — | — | — | — | — |
| 13SF-II | 48"#3Anth.<br>36"#612 Sand | 24 | 1.5 | 167 | 109 | 435 | 351 | 19.3 | 378 | 319 | 15.6 | 180 | 175 | 2.8 | 115 | 99 | 13.9 | 202 | 167 | 17.3 | 263 | 220 | 16.4 |
| 13SF-III | 48"#3Anth.<br>36"#612 Sand | 16 | 1.5 | 167 | 102 | 435 | 314 | 27.8 | 378 | 296 | 21.7 | 180 | 167 | 7.2 | 115 | 91 | 20.8 | 202 | 149 | 26.3 | 263 | 205 | 22.0 |
| 13SF-IV | 48"#3Anth.<br>36"#612 Sand | 10 | 1.5 | 167 | 100 | 435 | 318 | 26.8 | 378 | 265 | 30.0 | 180 | 136 | 24.4 | 115 | 82 | 28.7 | 202 | 162 | 19.9 | 263 | 183 | 30.5 |
| 14SF-I | 48"#3Anth.<br>36"#612 Sand | 16 | .5 | 111 | 67 | 301 | 262 | 12.9 | 280 | 240 | 14.3 | 118 | 95 | 19.5 | 116 | 99 | 14.6 | 139 | 112 | 19.4 | 164 | 141 | 14.0 |
| 14ASF-I | 48"#3Anth.<br>36"#612 Sand | 32 | .5 | 62 | 46 | 386 | 371 | 3.9 | 204 | 227 | 0 | — | | — | 73 | 78 | 0 | — | — | — | 131 | 149 | 0 |

| | | | | Total Suspended Solids | | | | | | Volatile Suspended Solids | | | | | | Nonvolatile Suspended Solids | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | | Grab | | | Composite | | | Grab | | | Composite | | | Grab | | | Composite | | |
| Run No. | Media | Flux Rate | Poly Feed | Inf. Avg | Eff. Avg | % Removal | Inf. | Eff. | % Removal | Inf. Avg. | Eff. Avg. | % Removal | Inf. | Eff. | % Removal | Inf. Avg. | Eff. Avg. | % Removal | Inf. | Eff. | % Removal |
| 13SF-II | 48"#3 Anth.<br>36"#612 Sand | 24 | 1.5 | 116 | 63 | 45.7 | — | — | — | 62 | 39 | 37.0 | — | — | — | 54 | 26 | 52.0 | — | — | — |
| 13SF-III | 48"#3 Anth.<br>36"#612 Sand | 16 | 1.5 | 116 | 37 | 68.0 | — | — | — | 62 | 23 | 63.0 | — | — | — | 54 | 12 | 78.0 | — | — | — |
| 13SF-IV | 48"#3 Anth.<br>36"# 612 Sand | 10 | 1.5 | 116 | 30 | 74.0 | — | — | — | 62 | 21 | 66.0 | — | — | — | 54 | 9 | 83.0 | — | — | — |
| 14SF-I | 48"#3 Anth.<br>36"#612 Sand | 16 | 0.5 | 81 | 49 | 41.0 | 110 | 45 | — | 48 | 13 | 31.2 | 71 | 34 | 52.0 | 36 | 16 | 56.0 | 39 | 11 | — |
| 14ASF-I | 48"#3 Anth.<br>36"#612 Sand | 32 | 0.5 | — | — | — | 86 | 50 | 31 | — | — | — | 70 | 46 | 33.5 | — | — | — | 17 | 13 | 20.5 |

# TABLE B-6 (SHEET No.1)
# COMBINED SEWER OVERFLOW FILTRATION TESTS
# PHOSPHATE, NITROGEN AND GREASE REDUCTION BY FILTRATION
(1970 TEST DATA)

| | | | | Total Phosphate | | | | | | Soluble Phosphate | | | | | | Nitrogen | | | Grease | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | | Grab | | | Composite | | | Grab | | | Composite | | | Composite | | | Composite | | |
| Run No. | Media | Flow Flux gpm/ft$^2$ | Poly Feed mg/l | Inf. Avg. mg/l | Eff. Avg. mg/l | % Removal | Inf. Avg. mg/l | Eff. Avg. mg/l | % Removal | Inf. Avg. mg/l | Eff. Avg. mg/l | % Removal | Inf. Avg. mg/l | Eff. Avg. mg/l | % Removal | Inf. Avg. mg/l | Eff. Avg. mg/l | % Removal | Inf. Avg. mg/l | Eff. Avg. mg/l | % Removal |
| 4SF-II | 48"#4 Anth.<br>36"#612 Sand | 24 | 9 | — | — | — | — | — | — | — | — | — | — | — | — | — | — | — | — | — | — |
| 4SF-III | 40"#3Anth.<br>36"#612 Sand | 24 | 0 | — | — | — | 2.50 | 2.40 | 14.3 | — | — | — | — | — | — | 18.2 | 14.8 | 18.6 | — | — | — |
| 5SF-I | 48"#3Anth.<br>40"#612 Sand | 16 | 0 | — | — | — | — | — | — | — | — | — | — | — | — | — | — | — | — | — | — |
| 5SF-II | 40"#4 Anth.<br>36"#612 Sand | 16 | 0 | — | — | — | — | — | — | — | — | — | — | — | — | — | — | — | — | — | — |
| 5SF-III | 40"#.Anth.<br>36"#612 Sand | 16 | 0 | — | — | — | — | — | — | — | — | — | — | — | — | — | — | — | — | — | — |
| 6SF-I | 48"#3Anth.<br>36"#612 Sand | 24 | 0 | — | — | — | 0.75 | 0.40 | 46.6 | — | — | — | — | — | — | 23.2 | 24.9 | 0 | 16.2 | 19.3 | 0 |
| 6SF-III | 60"#3Anth.<br>36"#612Sand | 16 | 0 | — | — | — | 0.75 | 0.60 | 20.0 | — | — | — | — | — | — | 23.2 | 19.9 | 14.2 | 16.2 | 32.7 | 0 |
| 7SF-III | 60"#3Anth.<br>36"#612 Sand | 16 | 0 | — | — | — | 1.00 | 1.25 | 0 | — | — | — | — | — | — | 10.2 | 6.6 | 35.1 | 6.4 | 3.8 | 40.6 |
| 8SF-III | 60"#3Anth.<br>36"#612 Sand | 32 | 0 | — | — | — | — | — | — | — | — | — | — | — | — | — | — | — | — | — | — |
| 9SF-I | 48"#3Anth.<br>36"#612 Sand | 24 | 0 | — | — | — | 0.40 | 0.03 | 90.0 | — | — | — | — | — | — | 11.1 | 9.9 | 10.9 | 20.9 | 20.6 | 1.5 |
| 9SF-II | 48"#3Anth.<br>36"#612 Sand | 40 | 0 | — | — | — | 0.40 | — | — | — | — | — | — | — | — | 11.1 | — | — | — | — | — |
| 9SF-III | 60"#3Anth.<br>36"#612 Sand | 10 | 0 | — | — | — | 0.40 | 0.30 | 85.5 | — | — | — | — | — | — | 11.1 | 8.4 | 24.2 | 20.9 | 7.5 | 44.2 |
| 9ASF-III | 60"#3Anth.<br>36"# 612Sand | 40 | 0 | — | — | — | — | — | — | — | — | — | — | — | — | — | — | — | — | — | — |

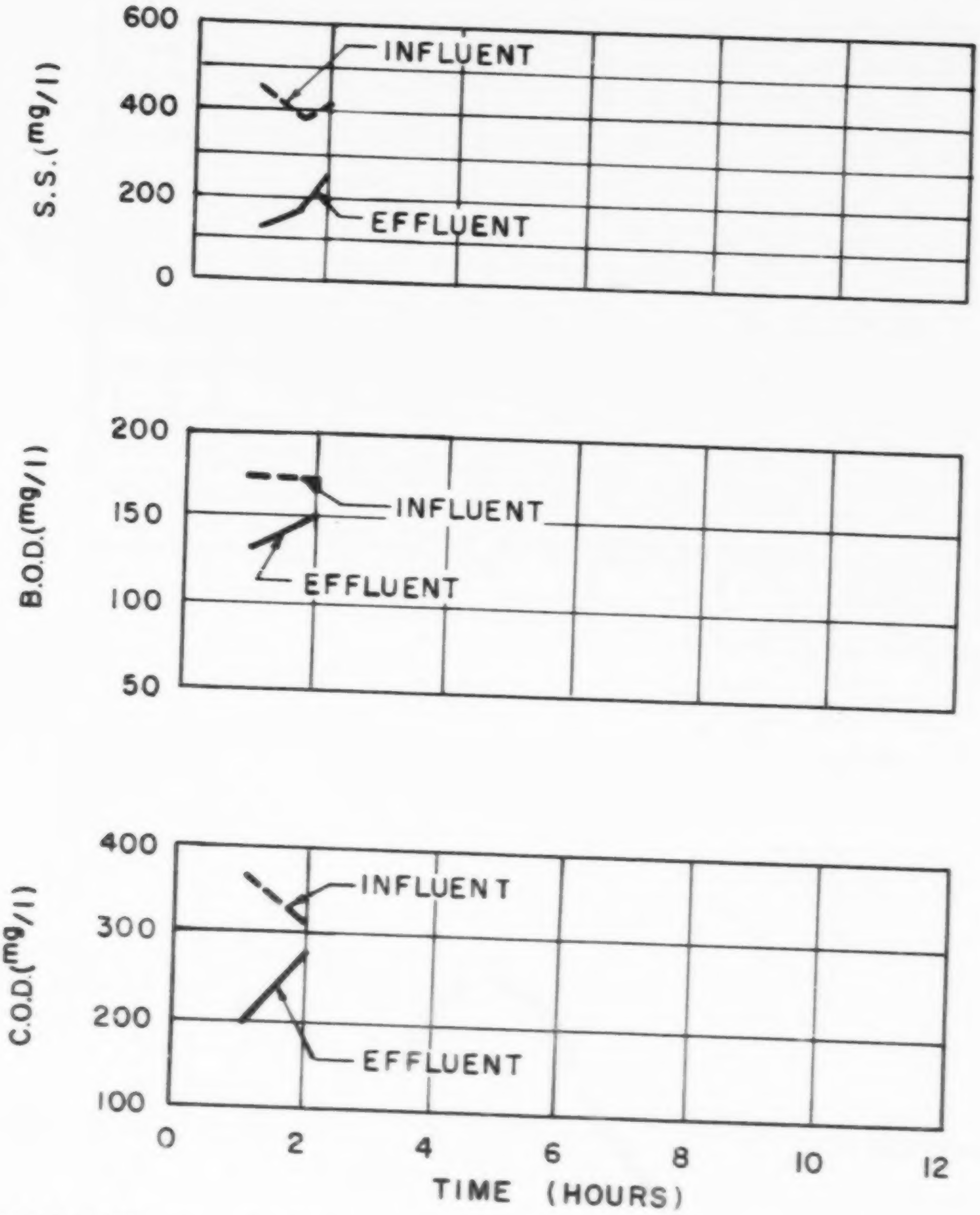
# TABLE B-6 (SHEET No.2)

# COMBINED SEWER OVERFLOW FILTRATION TESTS

# PHOSPHATE, NITROGEN AND GREASE REDUCTION BY FILTRATION

(1970 TEST DATA)

| | | | | Total Phosphate | | | | | | Soluble Phosphate | | | | | | Nitrogen | | | Grease | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | | Grab | | | Composite | | | Grab | | | Composite | | | Composite | | | Composite | | |
| Run No. | Media | Flow Flux gpm/ft² | Poly Feed mg/l | Inf. Avg. mg/l | Eff. Avg. mg/l | % Removal | Inf. Avg. mg/l | Eff. Avg. mg/l | % Removal | Inf. Avg. mg/l | Eff. Avg. mg/l | % Removal | Inf. Avg. mg/l | Eff. Avg. mg/l | % Removal | Inf. Avg. mg/l | Eff. Avg. mg/l | % Removal | Inf. Avg. mg/l | Eff. Avg. mg/l | % Removal |
| 10SF-I | 48"#3Anth.<br>36"#612 Sand | 32 | 0 | — | — | — | 1.6 | — | — | — | — | — | — | — | — | 8.7 | — | — | 25.5 | — | — |
| 10SF-II | 48"#3Anth.<br>36"#612 Sand | 16 | 0 | — | — | — | 1.6 | 1.3 | 18.7 | — | — | — | — | — | — | 8.7 | 7.0 | 19.5 | 25.5 | 13.9 | 45.5 |
| 10SF-III | 60"#3Anth.<br>36"#612 Sand | 24 | 0 | — | — | — | 1.6 | 1.3 | 18.7 | — | — | — | — | — | — | 8.7 | 7.0 | 19.5 | 25.5 | 18.5 | 27.4 |
| 10ASF-III | 60"#3Anth.<br>36"#612 Sand | 24 | .5 | — | — | — | — | — | — | — | — | — | — | — | — | — | — | — | — | — | — |
| 11SF-I | 48"#3Anth.<br>36"#612 Sand | 32 | .5 | — | — | — | 0.6 | 1.4 | 0 | — | — | — | — | — | — | 22.1 | 12.7 | 42.5 | 28.4 | 19.4 | 31.6 |
| 11SF-II | 48"#3Anth.<br>36"#612 Sand | 16 | 2.0 | — | — | — | 0.6 | 1.3 | 0 | — | — | — | — | — | — | 22.1 | 16.5 | 25.4 | 28.4 | 5.8 | 79.6 |
| 11SF-III | 60"#3Anth.<br>36"#612 Sand | 24 | 2.0 | — | — | — | 0.6 | 1.1 | 0 | — | — | — | — | — | — | 22.1 | 18.9 | 14.5 | 28.4 | 16.4 | 45.1 |
| 13SF-II | 48"#3Anth.<br>36"#612Sand | 24 | 1.5 | 10.5 | 6.6 | 37.1 | 6.0 | 6.8 | 0 | 4.1 | 3.7 | 9.7 | 4.0 | 4.4 | 0 | 7.7 | 6.7 | 13.0 | 10.9 | 47.5 | 0 |
| 13SF-III | 48"#3Anth.<br>36"#612Sand | 16 | 1.5 | 10.5 | 5.8 | 44.7 | 6.0 | 8.1 | 0 | 4.1 | 3.7 | 9.7 | 4.0 | 4.2 | 0 | 7.7 | 6.0 | 22.1 | 10.9 | 22.4 | 0 |
| 13SF-IV | 48"#3Anth.<br>36"#612 Sand | 10 | 1.5 | 10.5 | 6.8 | 35.1 | 6.0 | 5.4 | 10.0 | 4.1 | 3.5 | 14.7 | 4.0 | 4.2 | 0 | 7.7 | 5.3 | 31.1 | 10.9 | 5.5 | 49.5 |
| 14SF-I | 48"#3Anth<br>36"#612 Sand | 16 | 0.5 | 10.1 | 9.8 | 3.0 | 14.0 | 8.8 | 37.1 | 3.2 | 2.9 | 9.4 | 2.9 | 2.6 | 10.4 | 9.5 | 7.4 | 22. | 23.0 | 6.5 | 31.8 |
| *14ASF-I | 48"#3Anth.<br>36"#612 Sand | 32 | 0.5 | 11.1 | 11.9 | 0 | 11.0 | 11.0 | 0 | 28.3 | 3.8 | — | 6.0 | 4.9 | 18.3 | 10.2 | 11.1 | 0 | 40.4 | 27.5 | 43.2 |



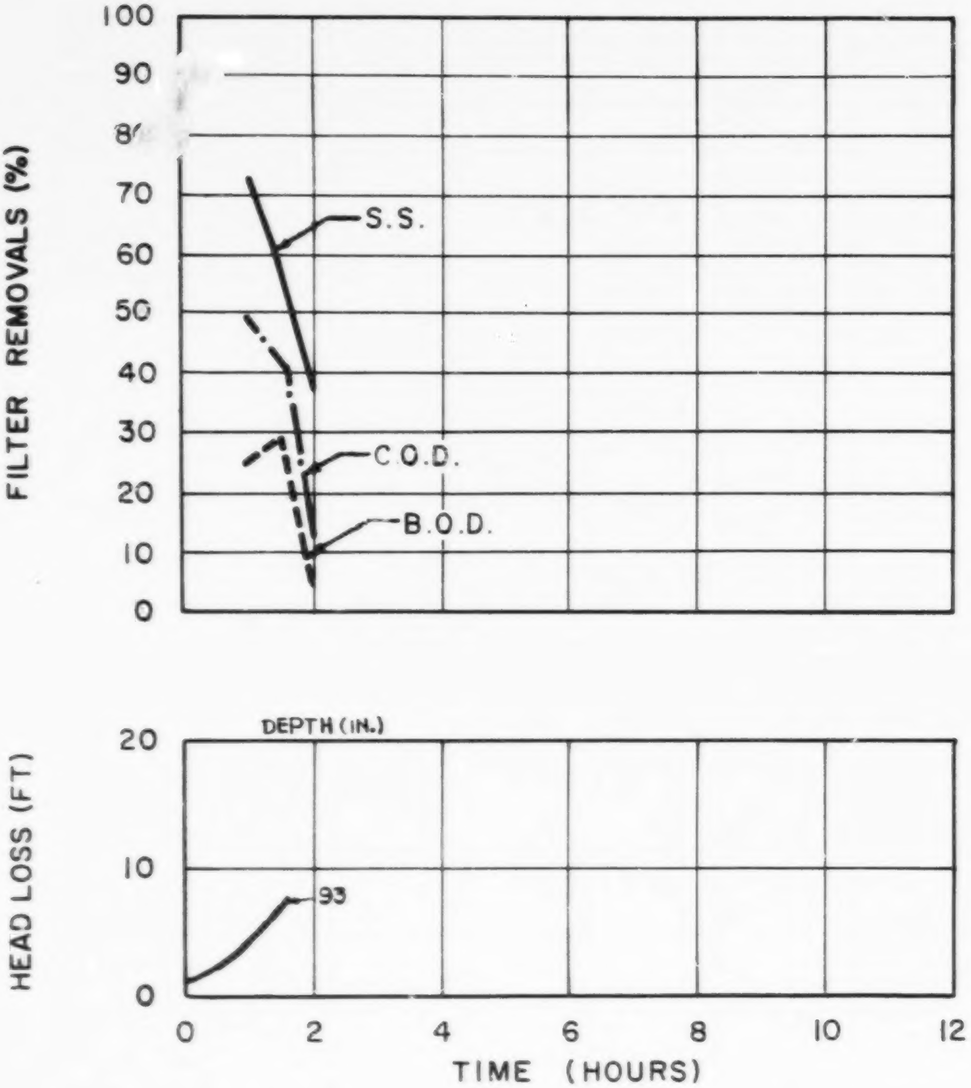
SCREEN 20 MESH. FILTER MEDIA 48 in. No. 4 ANTH./36 in. No. 612 SAND

DATE 9/3/70 FLUX RATE 24 gpm/ft²

RUN No. 4SFII

COMBINED SEWER OVERFLOW FILTRATION TEST

FIGURE C1



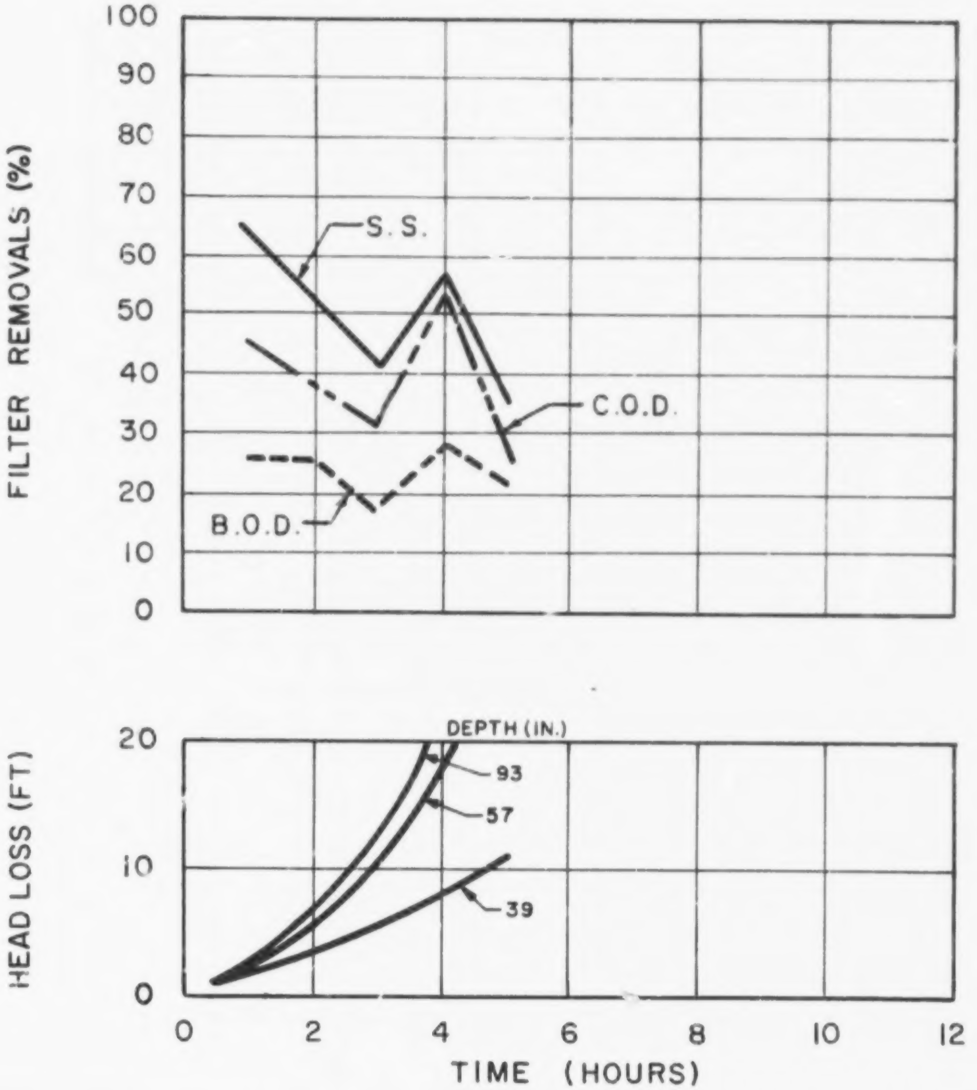
SCREEN 20 MESH. FILTER MEDIA 48 in. No. 4 ANTH./36 in. No. 612 SAND

DATE 9/3/70 FLUX RATE 24 gpm/ft²

RUN No. 4SFII

COMBINED SEWER OVERFLOW FILTRATION TEST

FIGURE C2



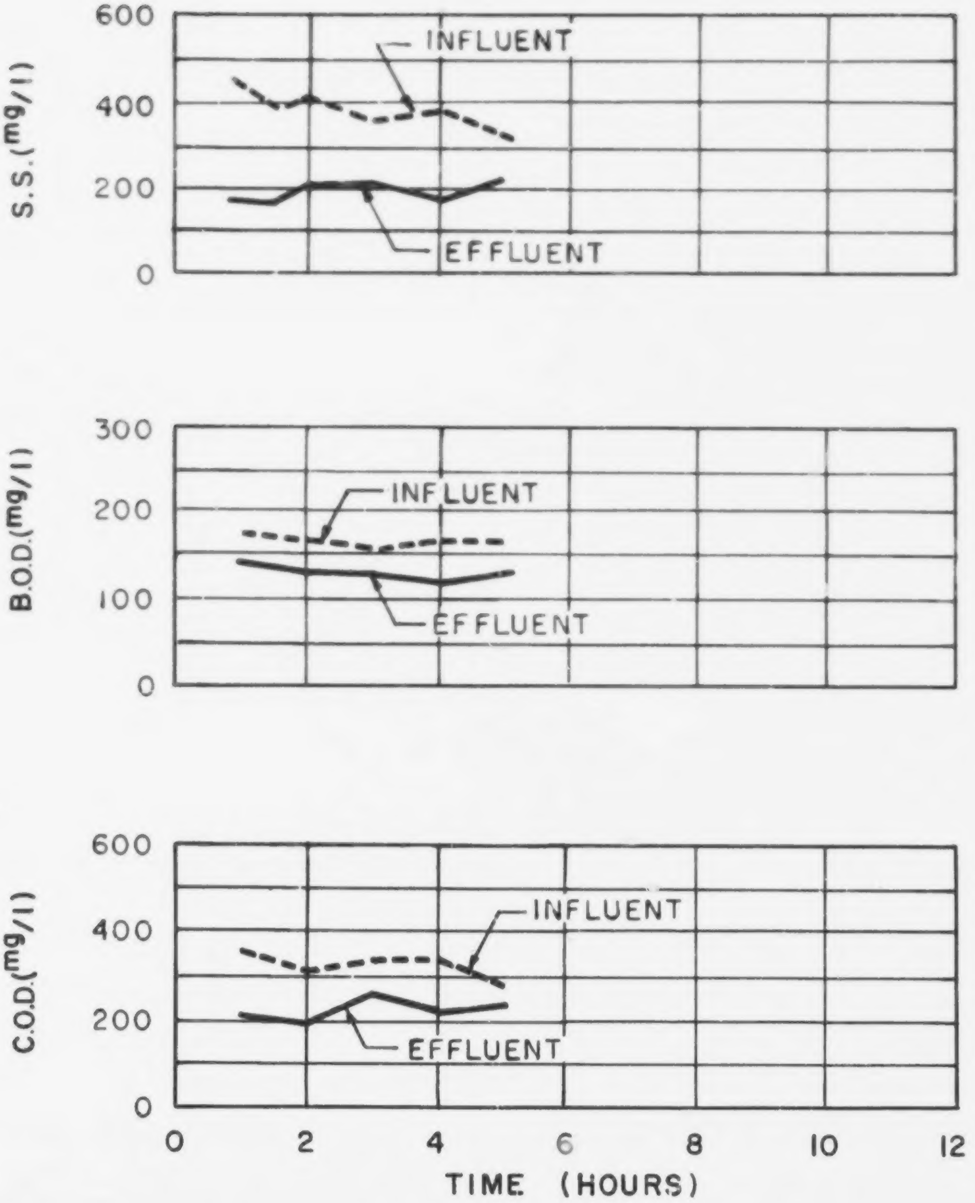
SCREEN 20 MESH. FILTER MEDIA 48 in. No. 3 ANTH./36 in. No. 612 SAND

DATE 9/3/70 FLUX RATE 24 gpm/ft$^2$

RUN No. 4SFIII

**COMBINED SEWER OVERFLOW FILTRATION TEST**

FIGURE C4



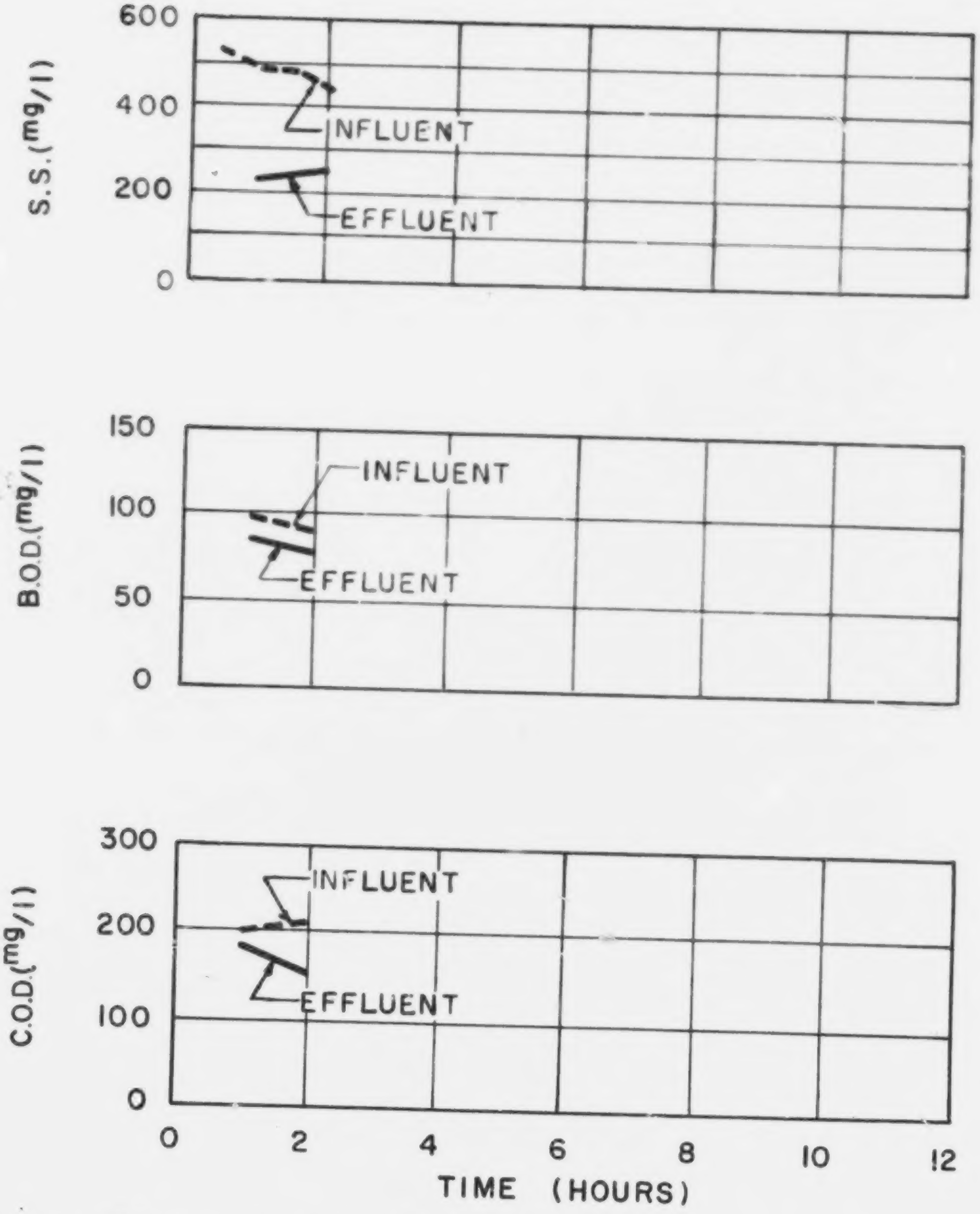
SCREEN 20 MESH. FILTER MEDIA 48 in. No. 4 ANTH./36 in. No. 612 SAND

DATE 9/3/70 FLUX RATE 24 gpm/ft$^2$

RUN No. 4SFIII

COMBINED SEWER OVERFLOW FILTRATION TEST

FIGURE C3



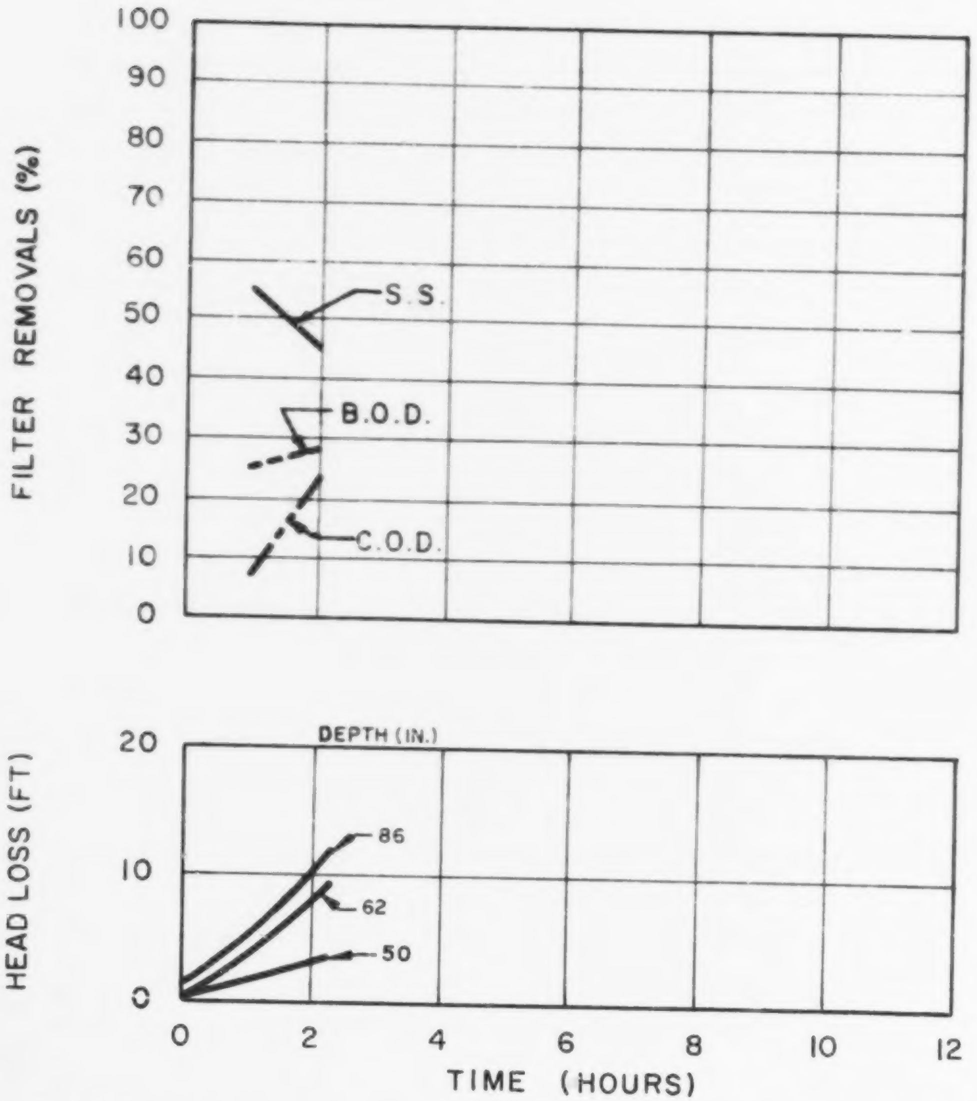
SCREEN 20 MESH. FILTER MEDIA 48 in. No. 4 ANTH./48 in. No. 612 SAND

DATE 9/8/70 FLUX RATE 16 gpm/ft$^2$

RUN No. 5SFI

COMBINED SEWER OVERFLOW FILTRATION TEST

FIGURE C5



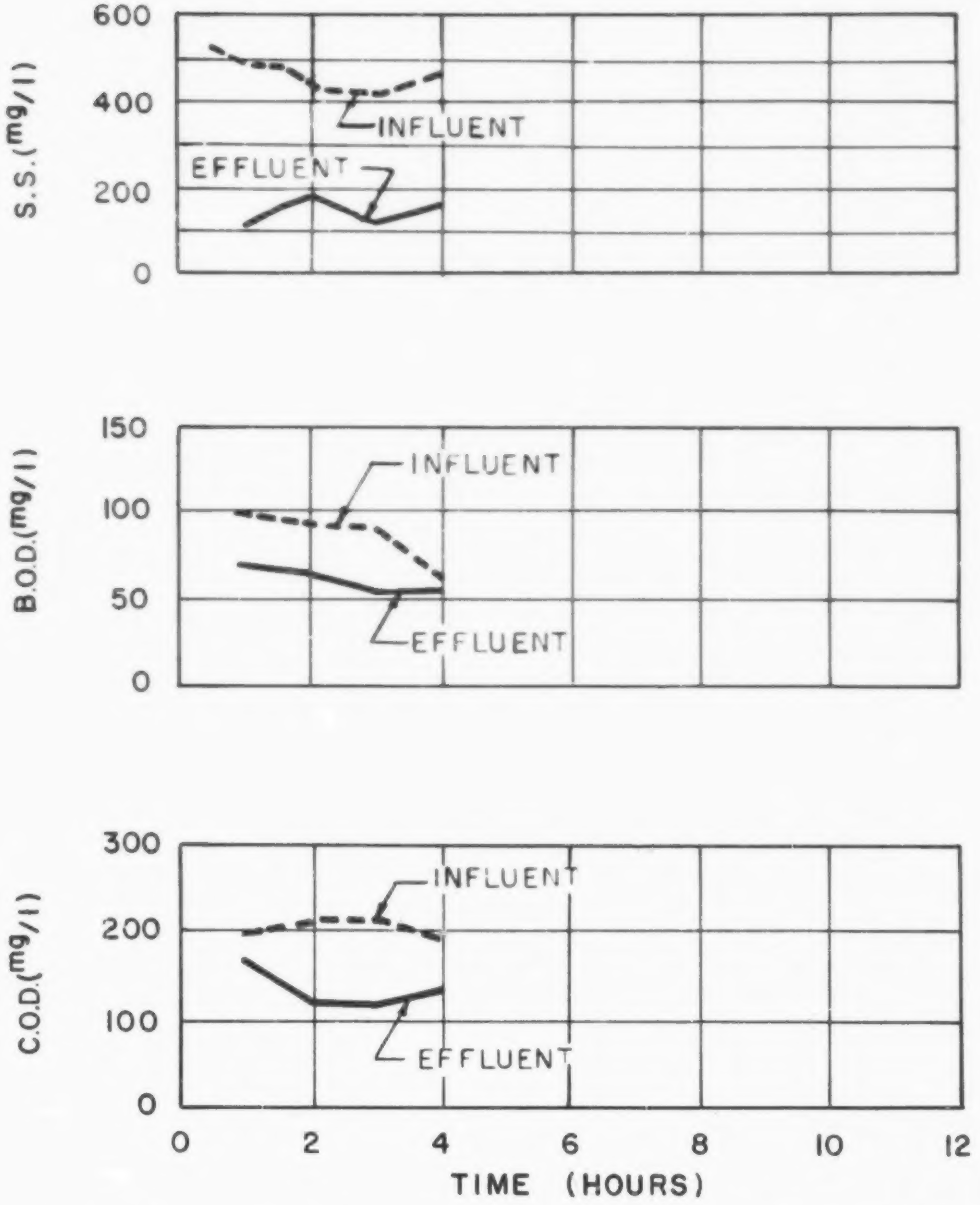
SCREEN 20 MESH. FILTER MEDIA 48 in. No. 4 ANTH./48 in. No. 612 SAND

DATE 9/8/70 FLUX RATE 16 gpm/ft$^2$

RUN No. 5SFI

COMBINED SEWER OVERFLOW FILTRATION TEST

FIGURE C6



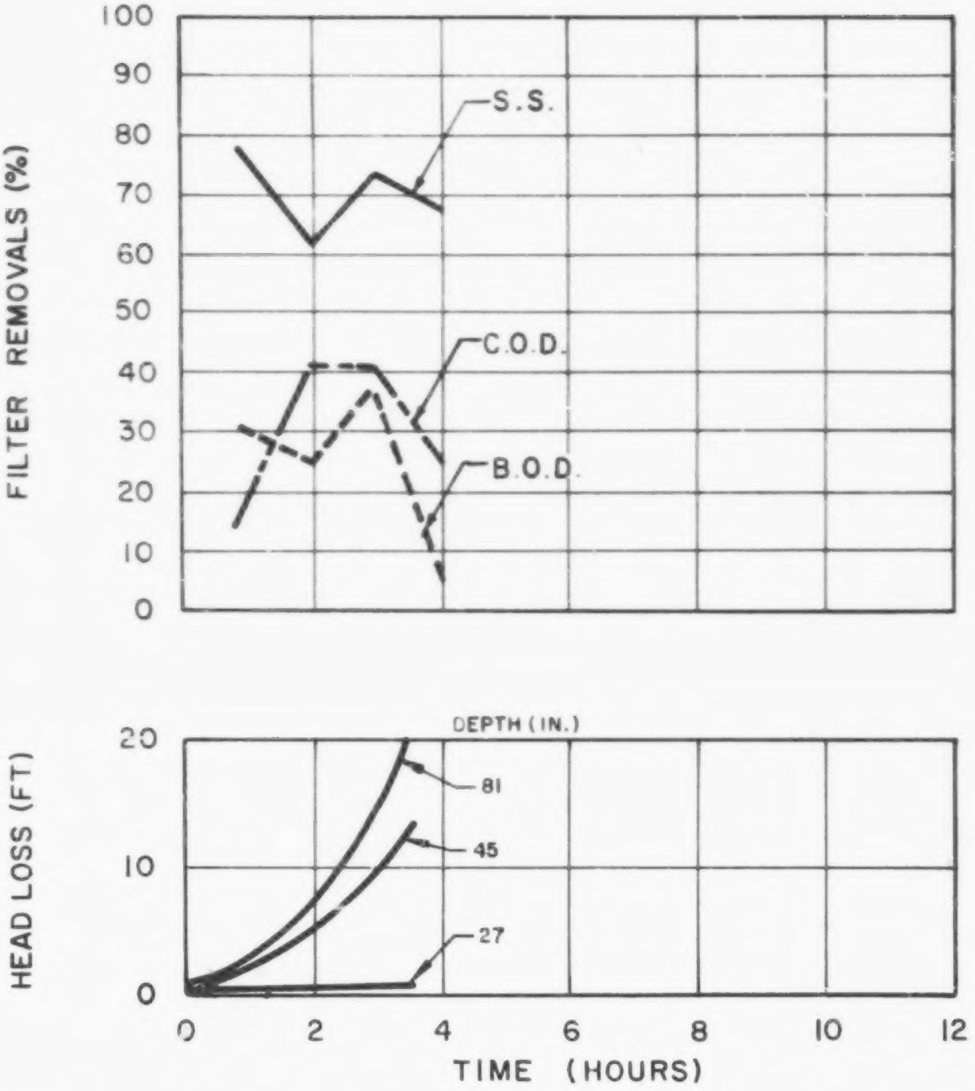
SCREEN 20 MESH. FILTER MEDIA 48 in. No. 4 ANTH. / 36 in. No. 612 SAND

DATE 9/8/70 FLUX RATE 16 gpm/ft$^2$

RUN No. 5SFII

COMBINED SEWER OVERFLOW FILTRATION TEST

FIGURE C7



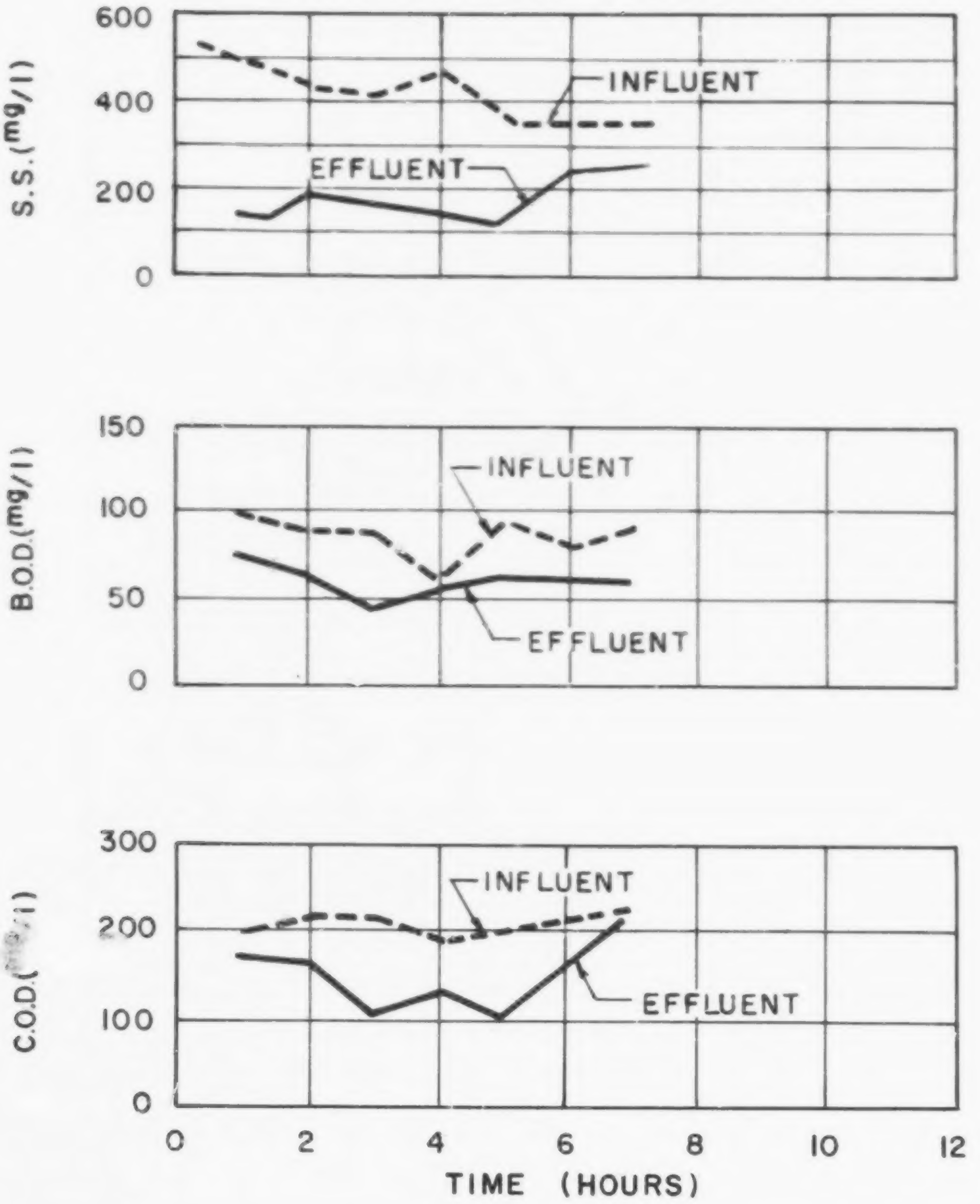
SCREEN 20 MESH. FILTER MEDIA. 48 in. No. 4 ANTH./ 36 in. No. 612 SAND

DATE 9/8/70 FLUX RATE 16 gpm/ft$^2$

RUN No. 5SF11

**COMBINED SEWER OVERFLOW FILTRATION TEST**

FIGURE C8



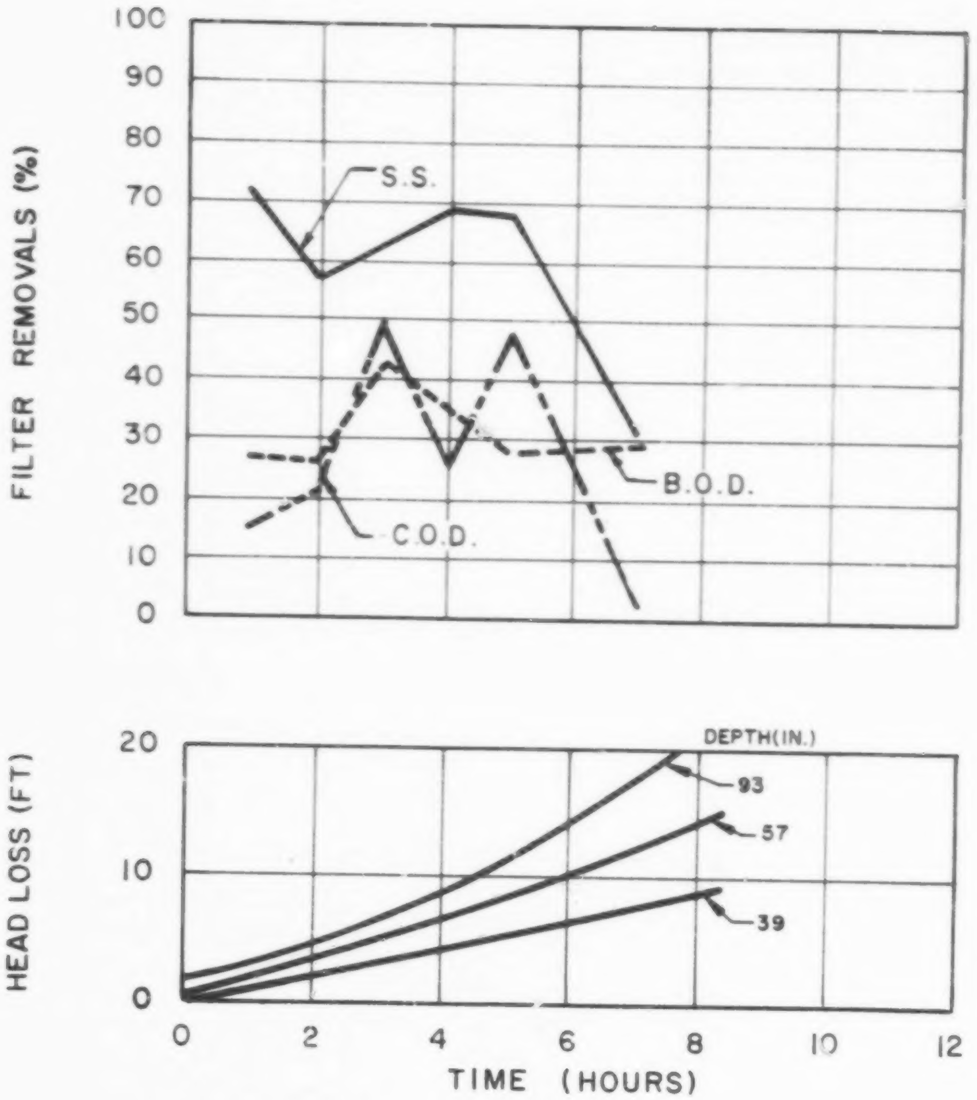
SCREEN 20 MESH. FILTER MEDIA 48 in. No. 3 ANTH./ 36 in. No. 612 SAND

DATE 9/8/70 FLUX RATE 16 gpm/ft$^2$

RUN No. 5SFIII

COMBINED SEWER OVERFLOW FILTRATION TEST

FIGURE C9



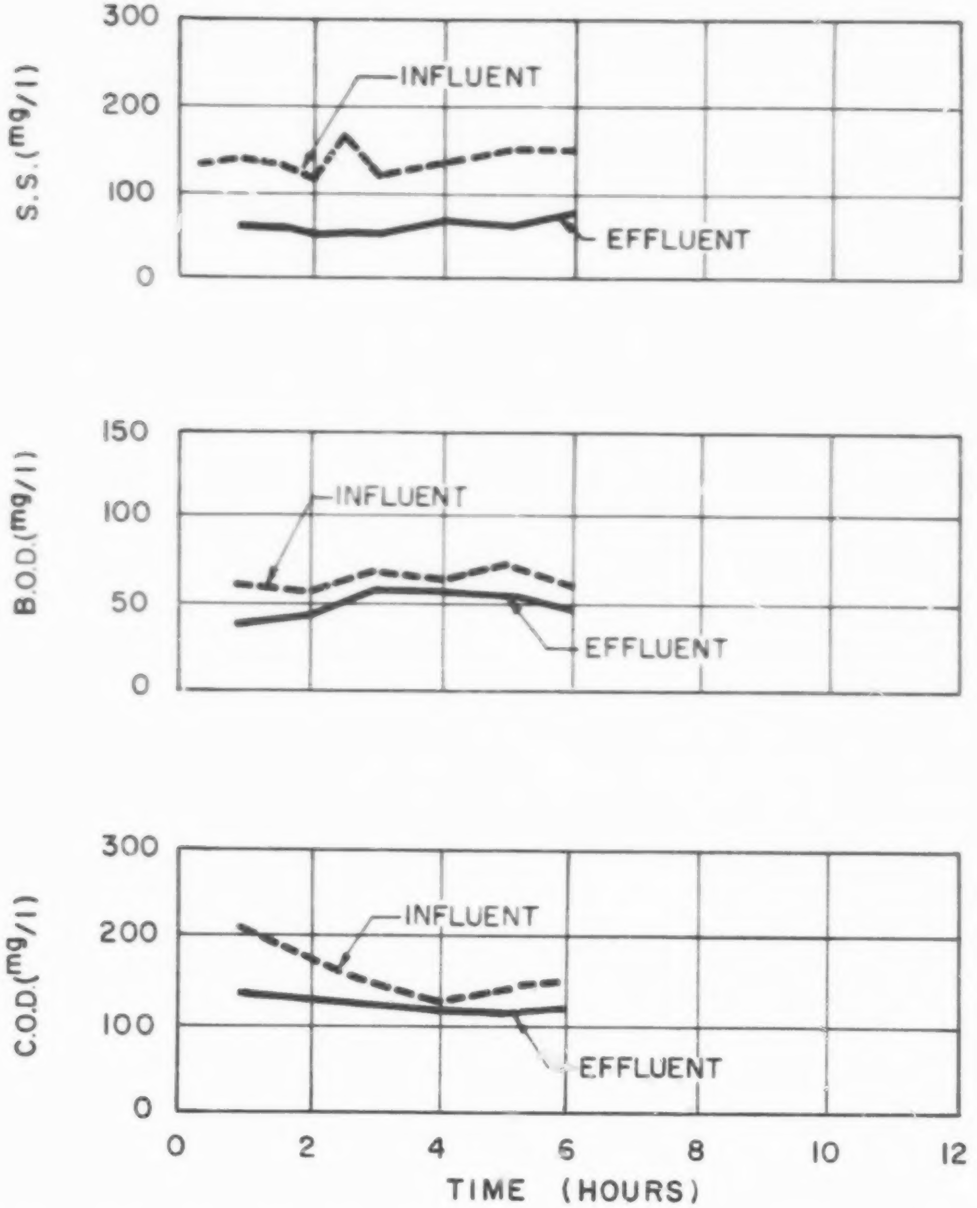
SCREEN 20 MESH. FILTER MEDIA 48 in. No. 3 ANTH./36 in. No. 612 SAND

DATE 9/8/70 FLUX RATE 16 gpm/ft$^2$

RUN No. 5SFIII

COMBINED SEWER OVERFLOW FILTRATION TEST

FIGURE C10



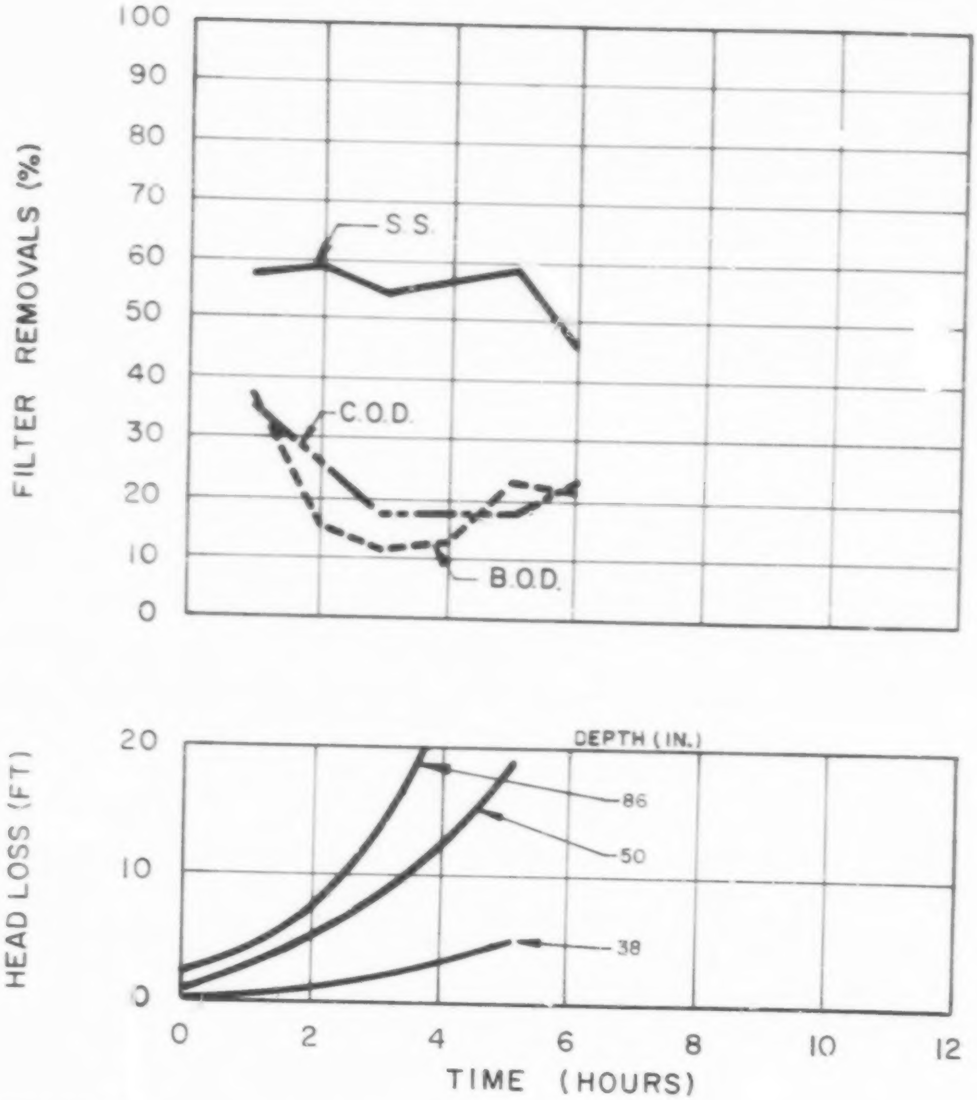
SCREEN 20 MESH. FILTER MEDIA 48 in. No. 3 ANTH./36 in. No. 612 SAND

DATE 9/19/70 FLUX RATE 24 gpm/ft$^2$

RUN No. 6SFI

**COMBINED SEWER OVERFLOW FILTRATION TEST**

**FIGURE C11**



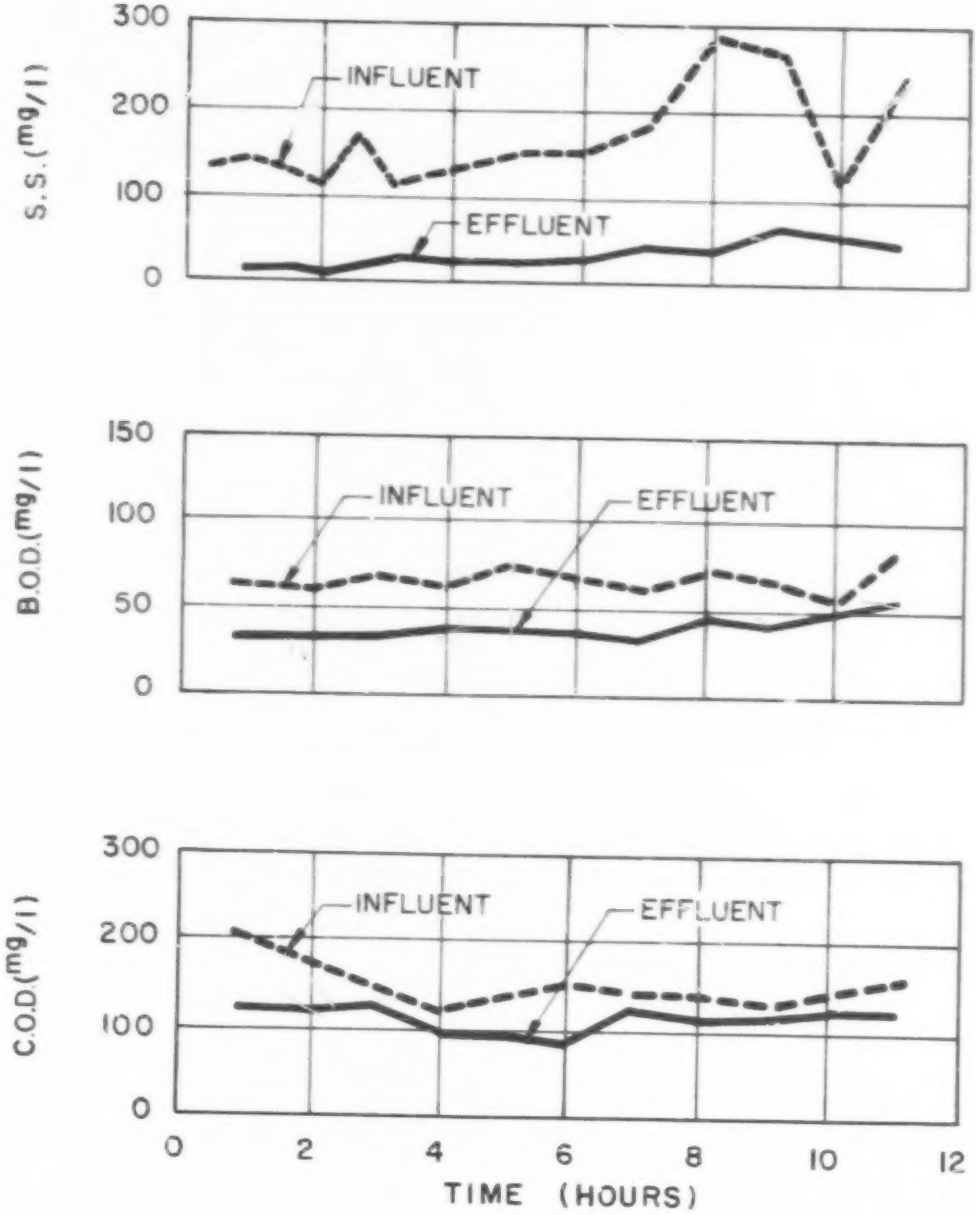
SCREEN 20 MESH. FILTER MEDIA 48 in. No. 3 ANTH./36 in. No. 612 SAND

DATE 9/19/70 FLUX RATE 24 gpm/ft$^2$

RUN No. 6SF1

## COMBINED SEWER OVERFLOW FILTRATION TEST

FIGURE C12



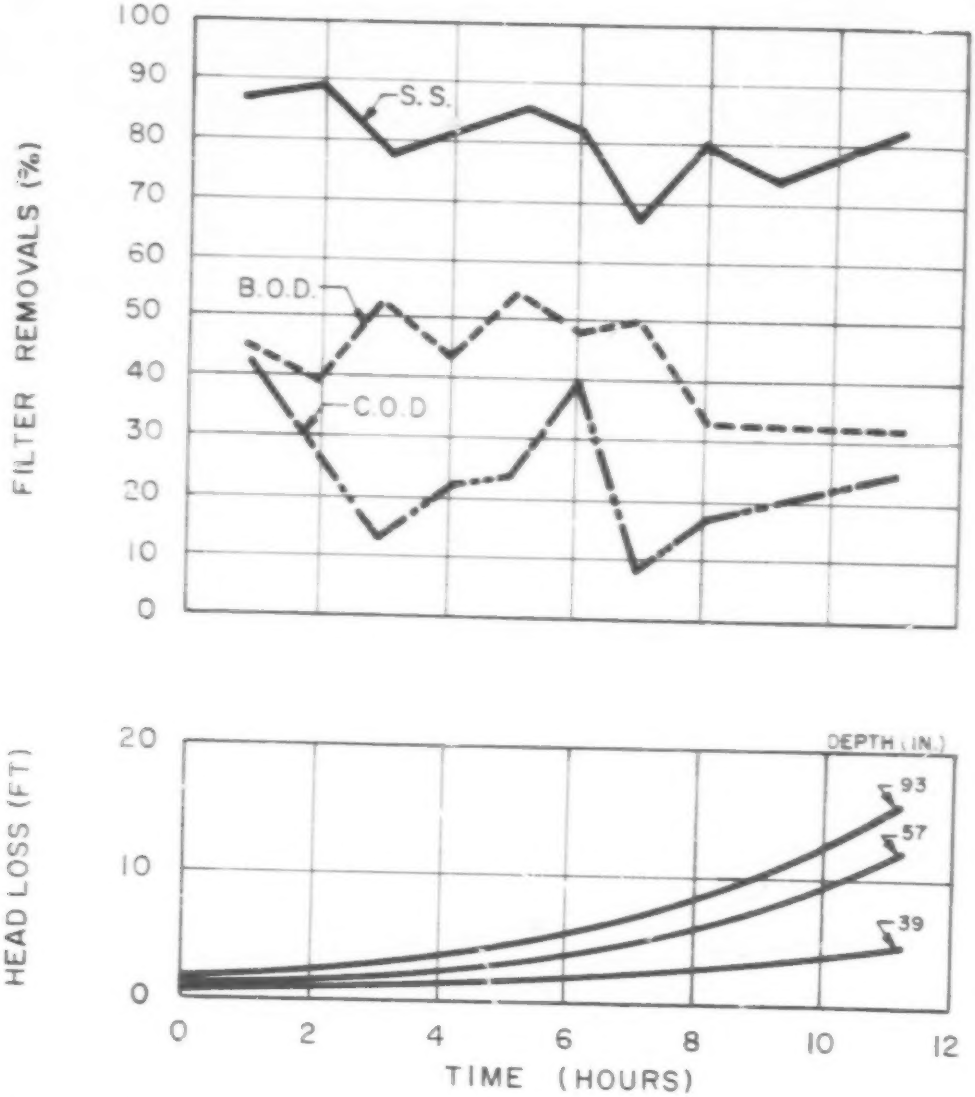
SCREEN 20 MESH. FILTER MEDIA 60 in. No. 3 ANTH./36 in. No. 612 SAND

DATE 9/19/70 FLUX RATE 16 gpm/ft²

RUN No. 6SFIII

COMBINED SEWER OVERFLOW FILTRATION TEST

FIGURE C13



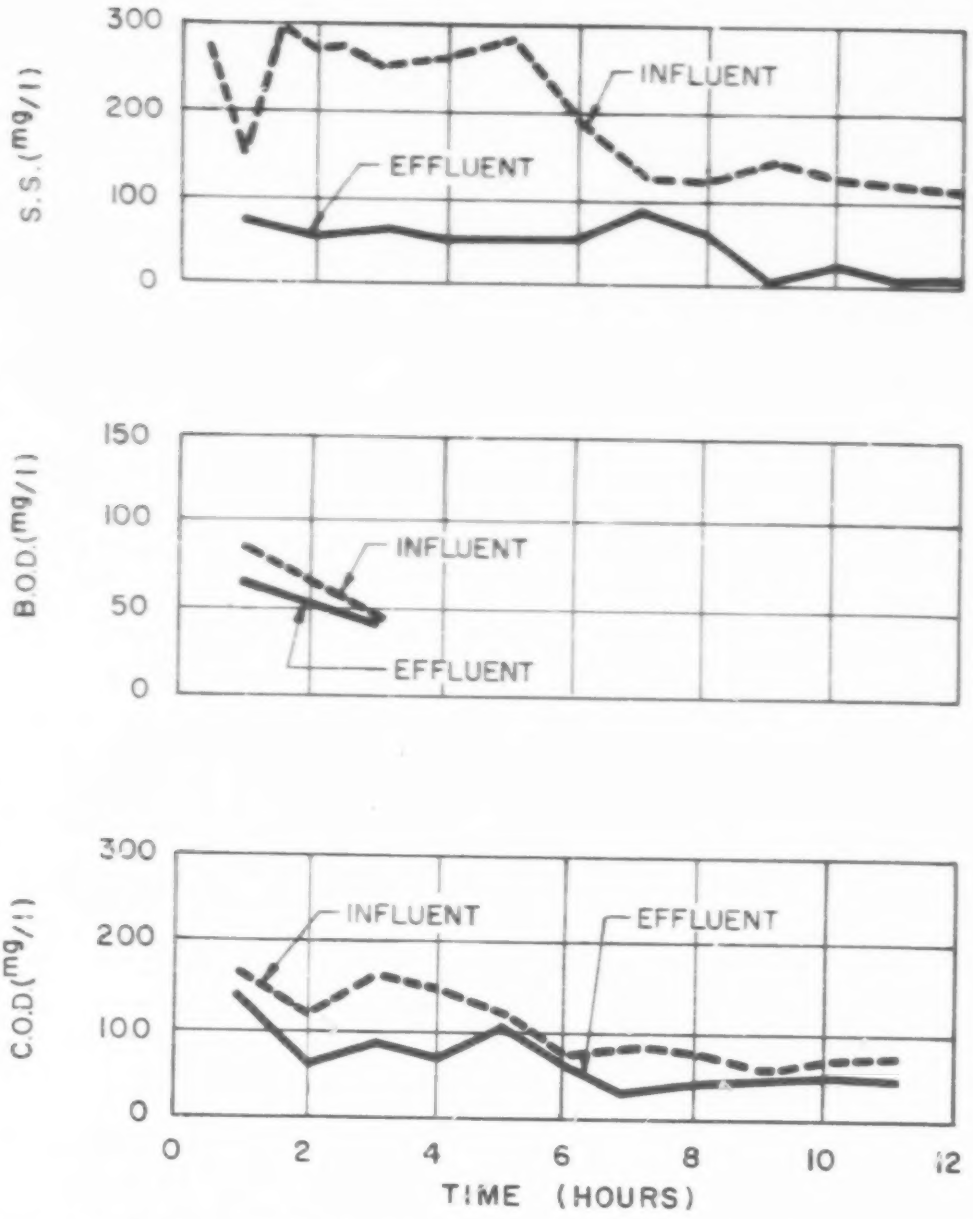
SCREEN 20 MESH. FILTER MEDIA 60 in. No. 3 ANTH./36 in. No. 612 SAND

DATE 9/19/70 FLUX RATE 16 gpm/ft²

RUN No. 6SFIII

COMBINED SEWER OVERFLOW FILTRATION TEST

FIGURE C14



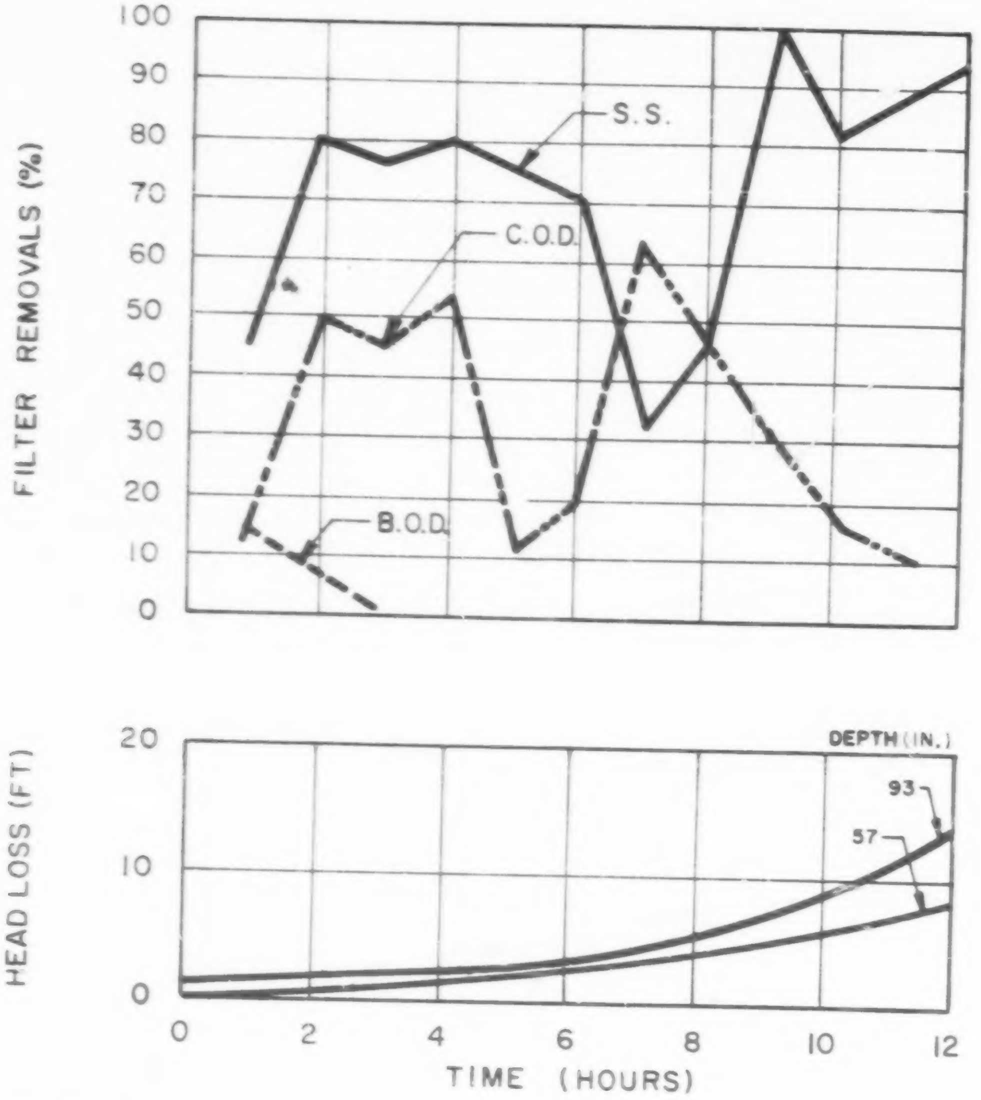
SCREEN 40 MESH FILTER MEDIA 60 in. No. 3 ANTH./36 in. No. 612 SAND.

DATE 9/23/70 FLUX RATE 16 gpm/ft$^2$

RUN No. 7SF III

**COMBINED SEWER OVERFLOW FILTRATION TEST**

**FIGURE C15**



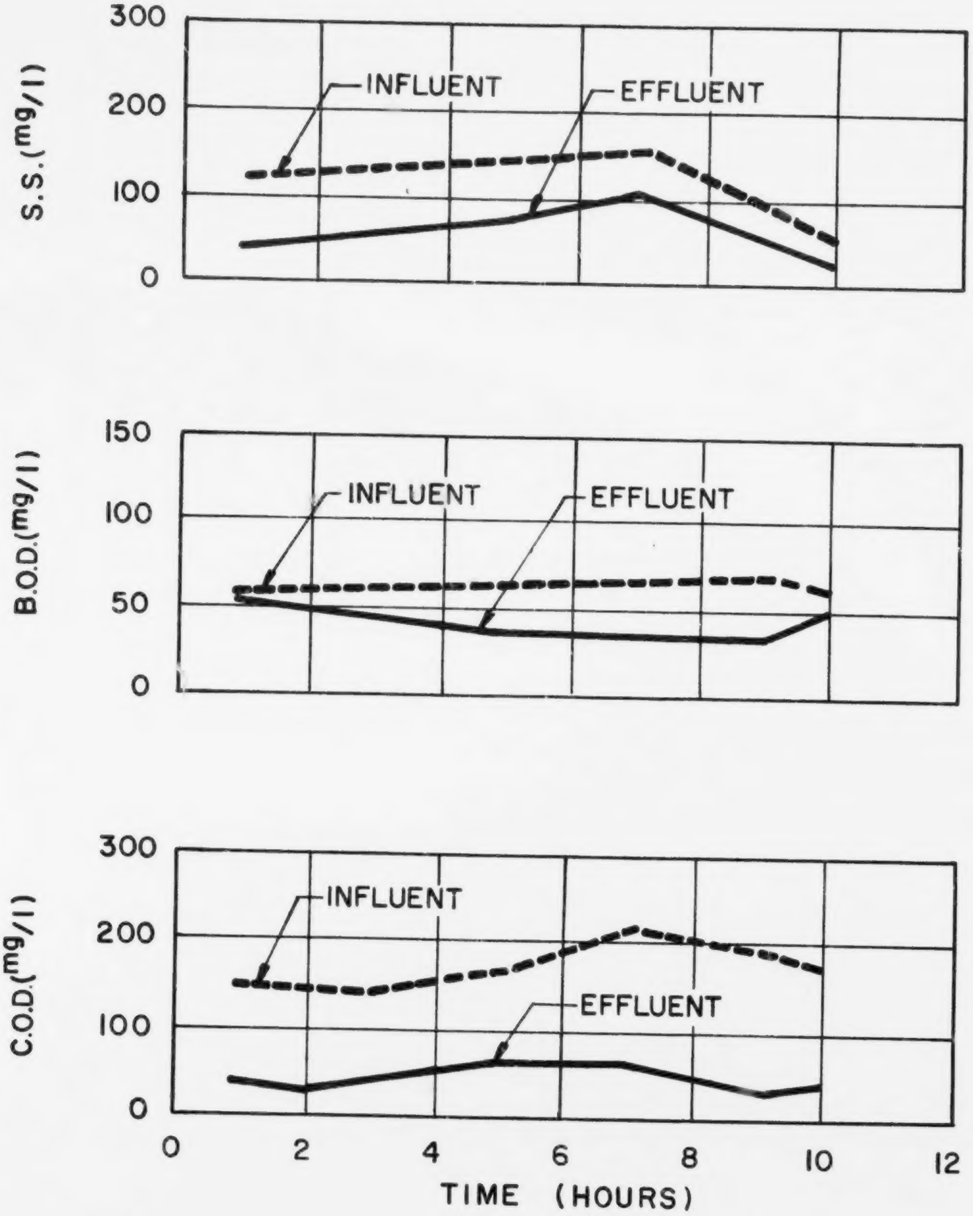
SCREEN 40 MESH. FILTER MEDIA 60 in. No. 3 ANTH./36 in. No. 612 SAND

DATE 9/23/70 FLUX RATE 16 gpm/ft²

RUN No. 7SF III

COMBINED SEWER OVERFLOW FILTRATION TEST

FIGURE C16



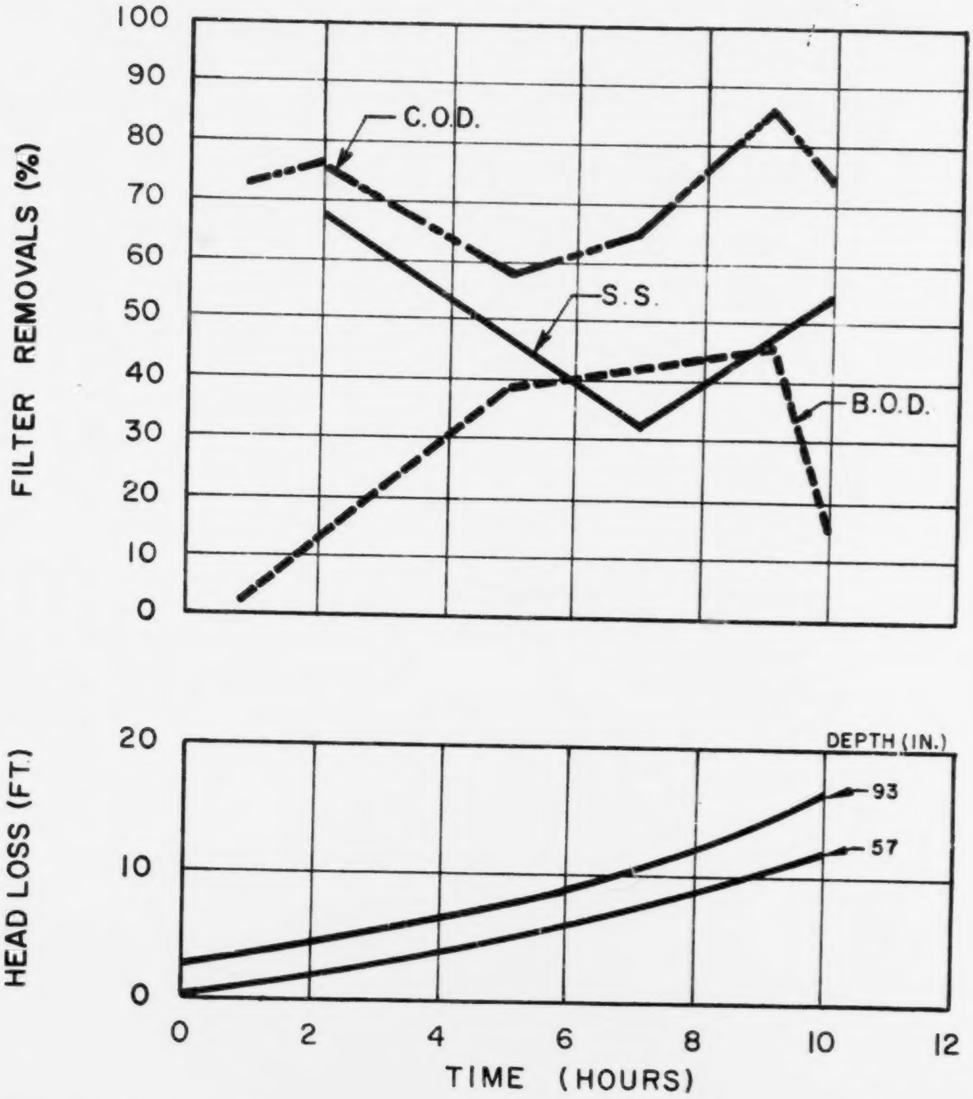
SCREEN 40 MESH. FILTER MEDIA 60 in. No. 3 ANTH./36 in. No. 612 SAND

DATE 9/28/70 FLUX RATE 32 gpm/ft$^2$

RUN No. 8SFIII

COMBINED SEWER OVERFLOW FILTRATION TEST

FIGURE C17



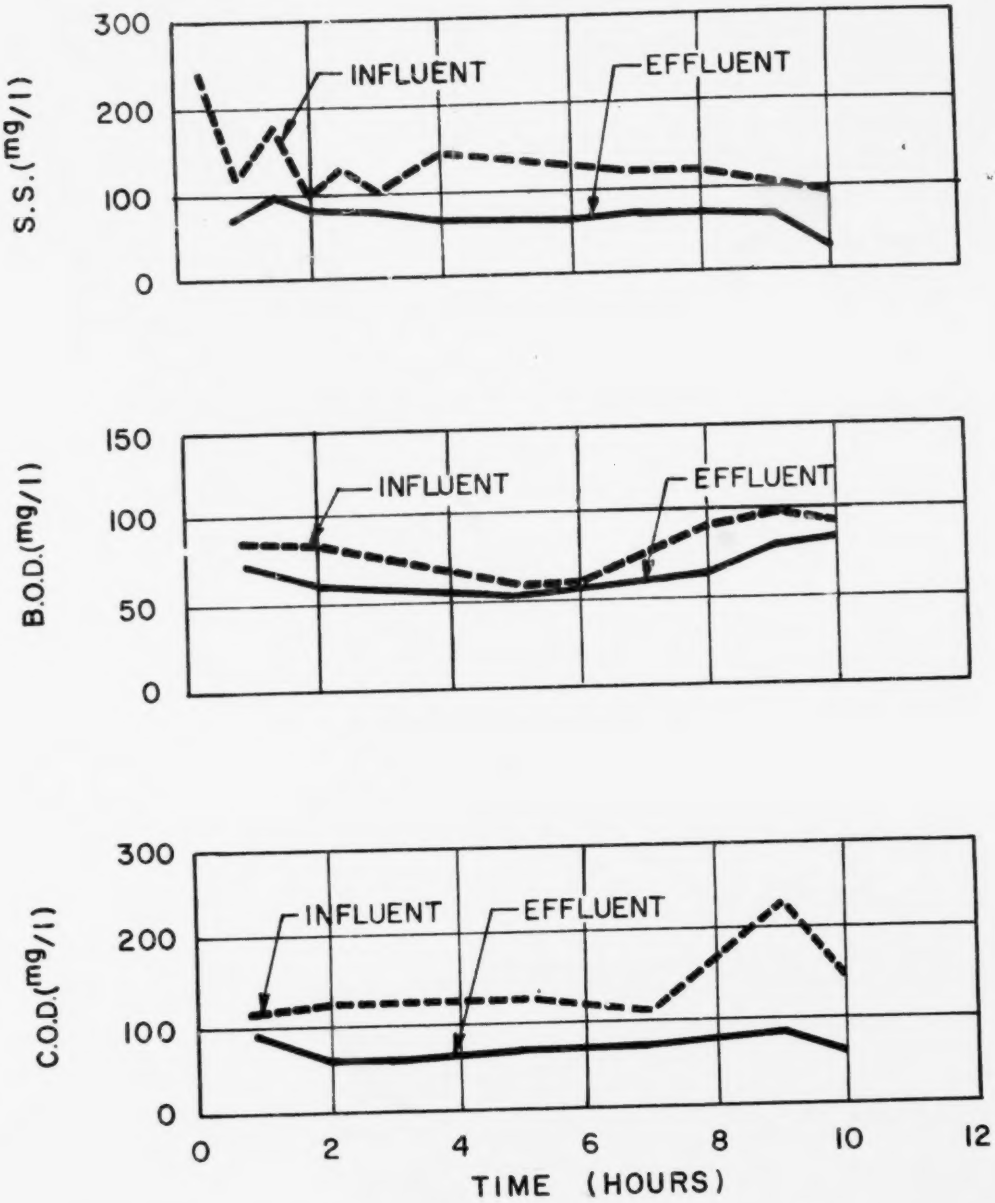
SCREEN 40 MESH. FILTER MEDIA 60 in. No. 3 ANTH./ 36 in. No. 612 SAND

DATE 9/28/70 FLUX RATE 32 gpm/ft²

RUN No. 8SFIII

**COMBINED SEWER OVERFLOW FILTRATION TEST**

FIGURE C18



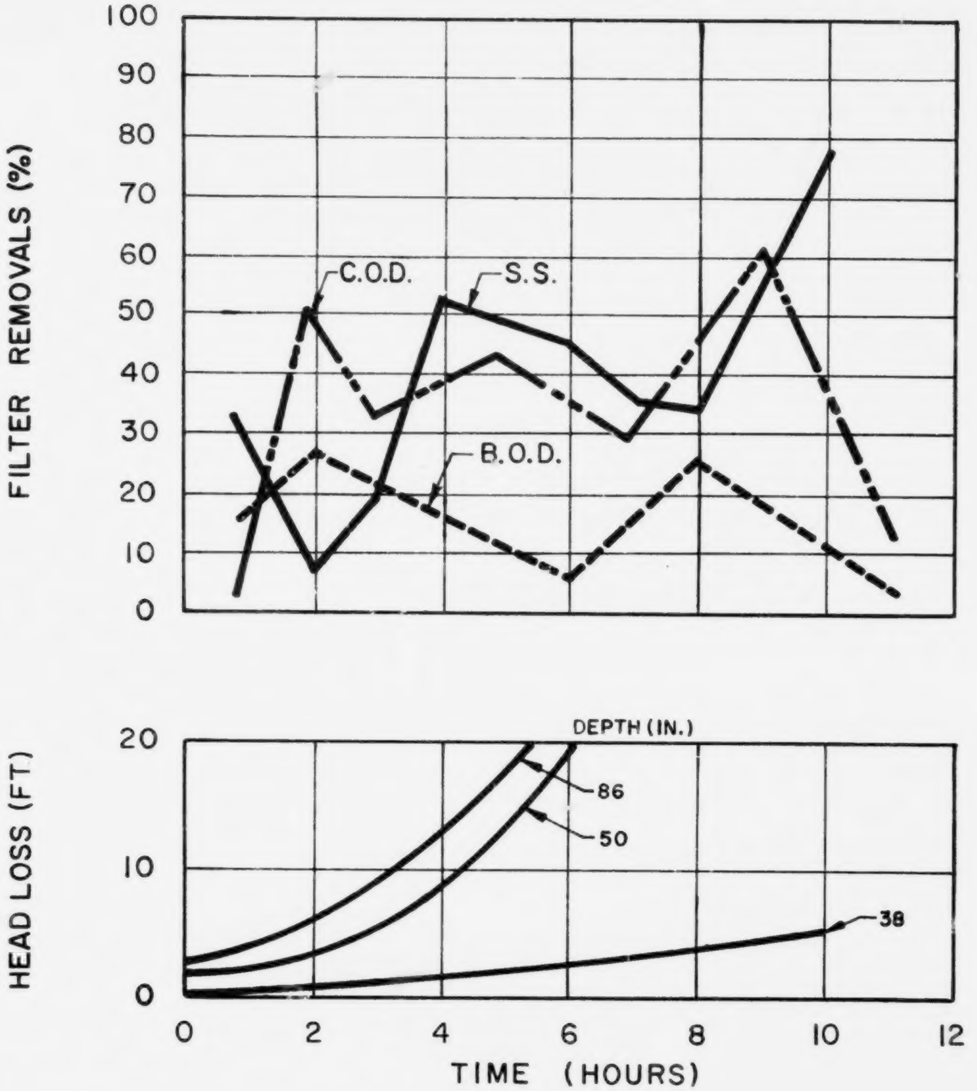
SCREEN 40 MESH. FILTER MEDIA 48 in. No. 3 ANTH./ 36 in. No. 612 SAND

DATE 10/6/70 FLUX RATE 24 gpm/ft$^2$

RUN No. 9SFI

COMBINED SEWER OVERFLOW FILTRATION TEST

FIGURE C19



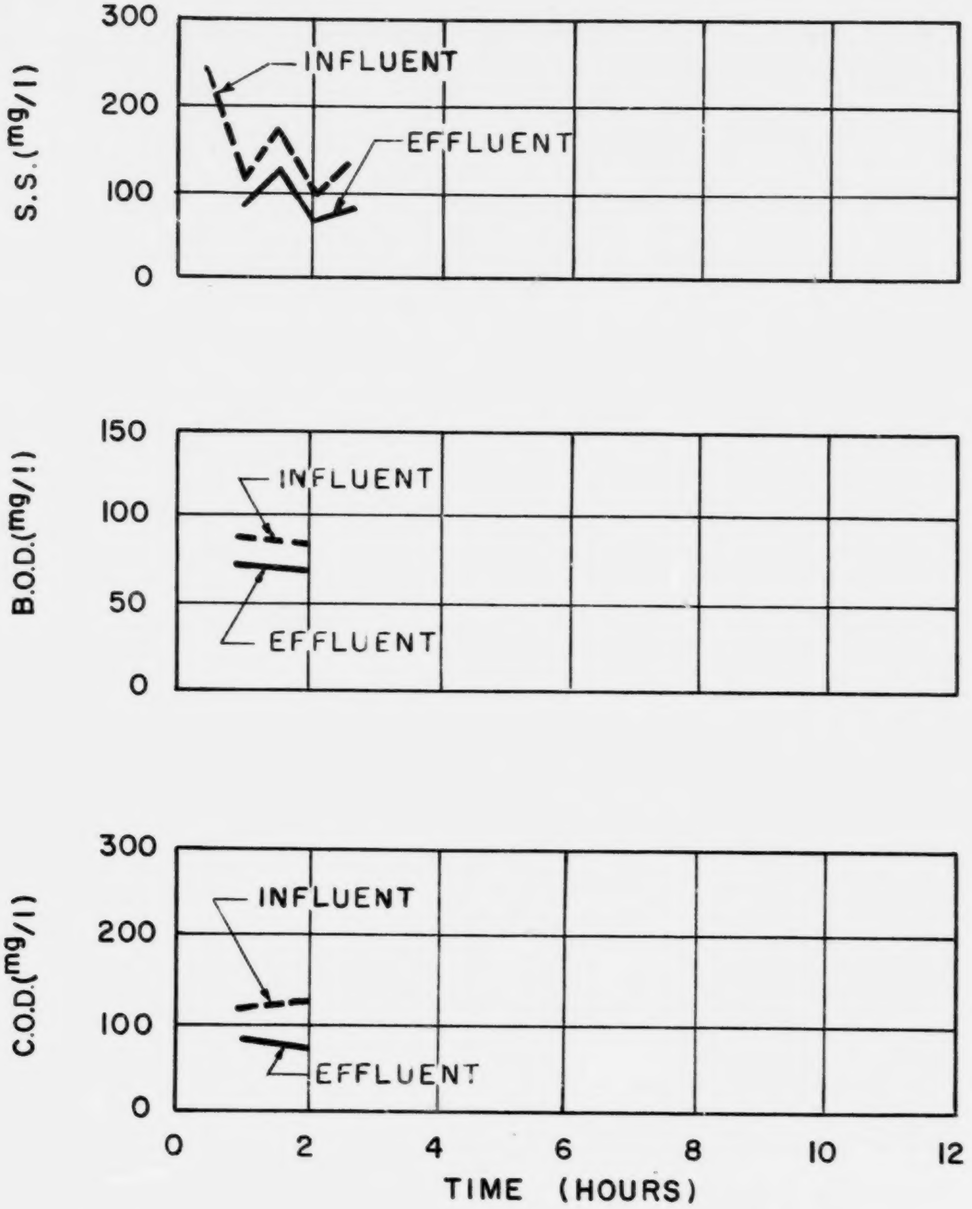
SCREEN 40 MESH. FILTER MEDIA 48 in. No. 3 ANTH./ 36 in. No. 612 SAND

DATE 10/6/70 FLUX RATE 24 gpm/ft²

RUN No. 9SFI

COMBINED SEWER OVERFLOW FILTRATION TEST

FIGURE C20



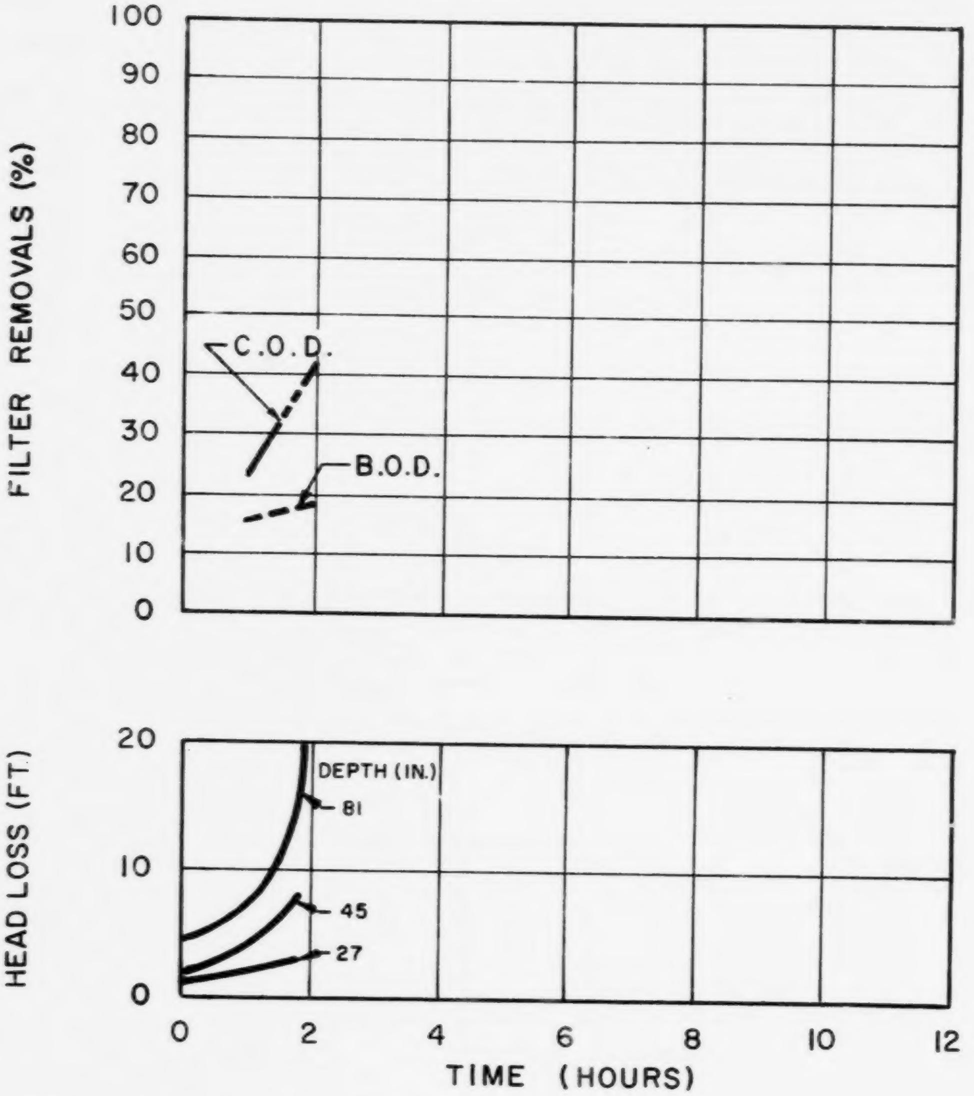
SCREEN 40 MESH. FILTER MEDIA 48 in. No. 3 ANTH./36 in. No. 612 SAND

DATE 10/6/70 FLUX RATE 40 gpm/ft$^2$

RUN No. 9SFII

**COMBINED SEWER OVERFLOW FILTRATION TEST**

**FIGURE C21**



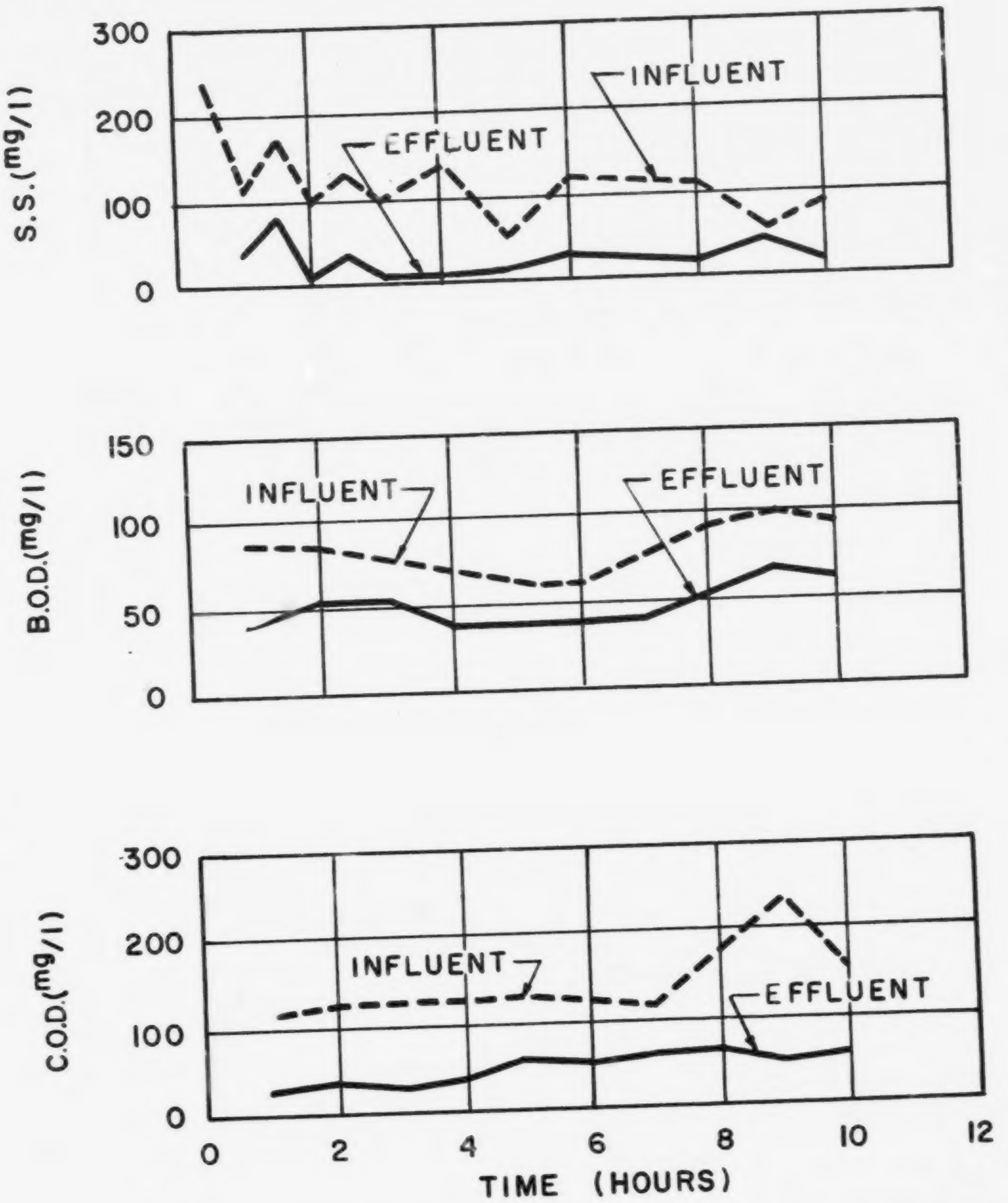
SCREEN 40 MESH. FILTER MEDIA 48 in. No. 3 ANTH./36 in. No. 612 SAND

DATE 10/6/70 FLUX RATE 40 gpm/ft$^2$

RUN No. 9SFII

**COMBINED SEWER OVERFLOW FILTRATION TEST**

FIGURE C22



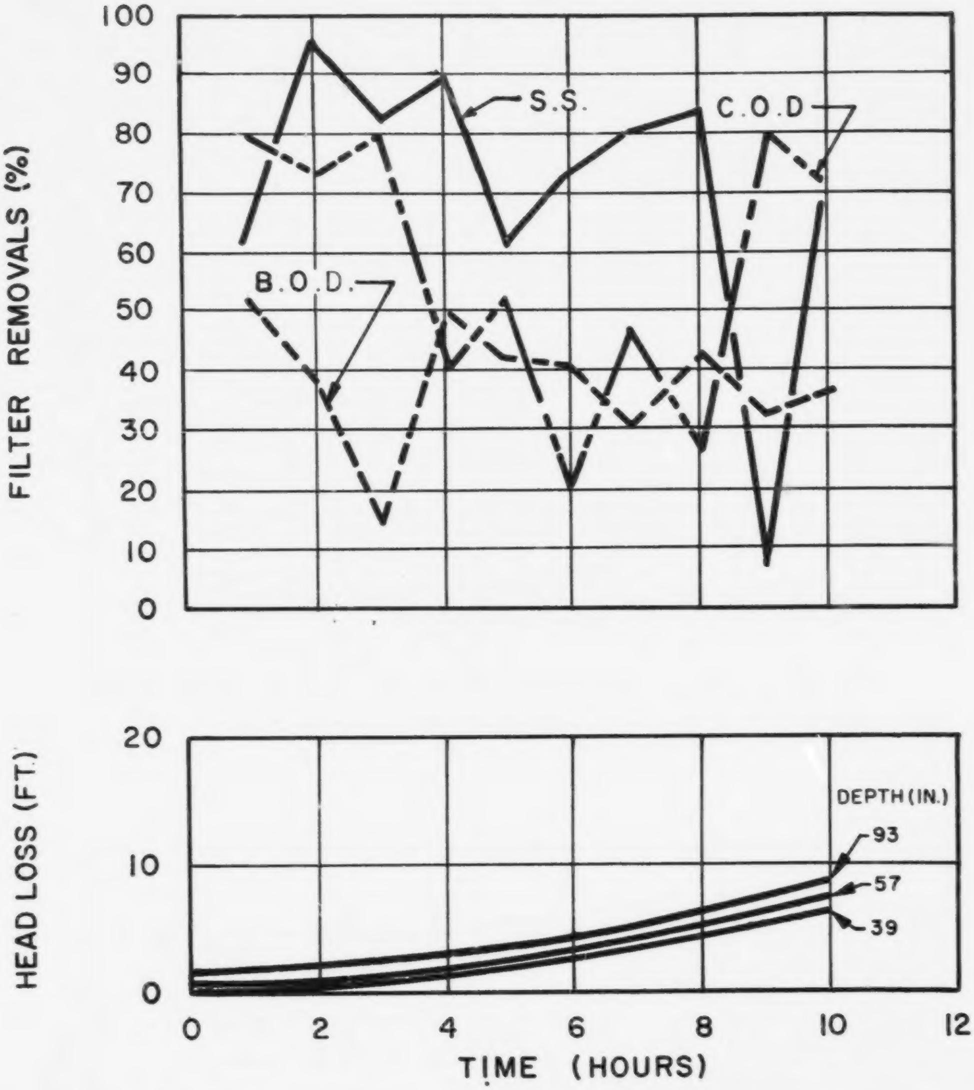
SCREEN 40 MESH. FILTER MEDIA 60 in. No. 3 ANTH./36 in. No. 612 SAND

DATE 10/6/70 FLUX RATE 10 gpm/ft$^2$

RUN No. 9SFIII

COMBINED SEWER OVERFLOW FILTRATION TEST

FIGURE C23



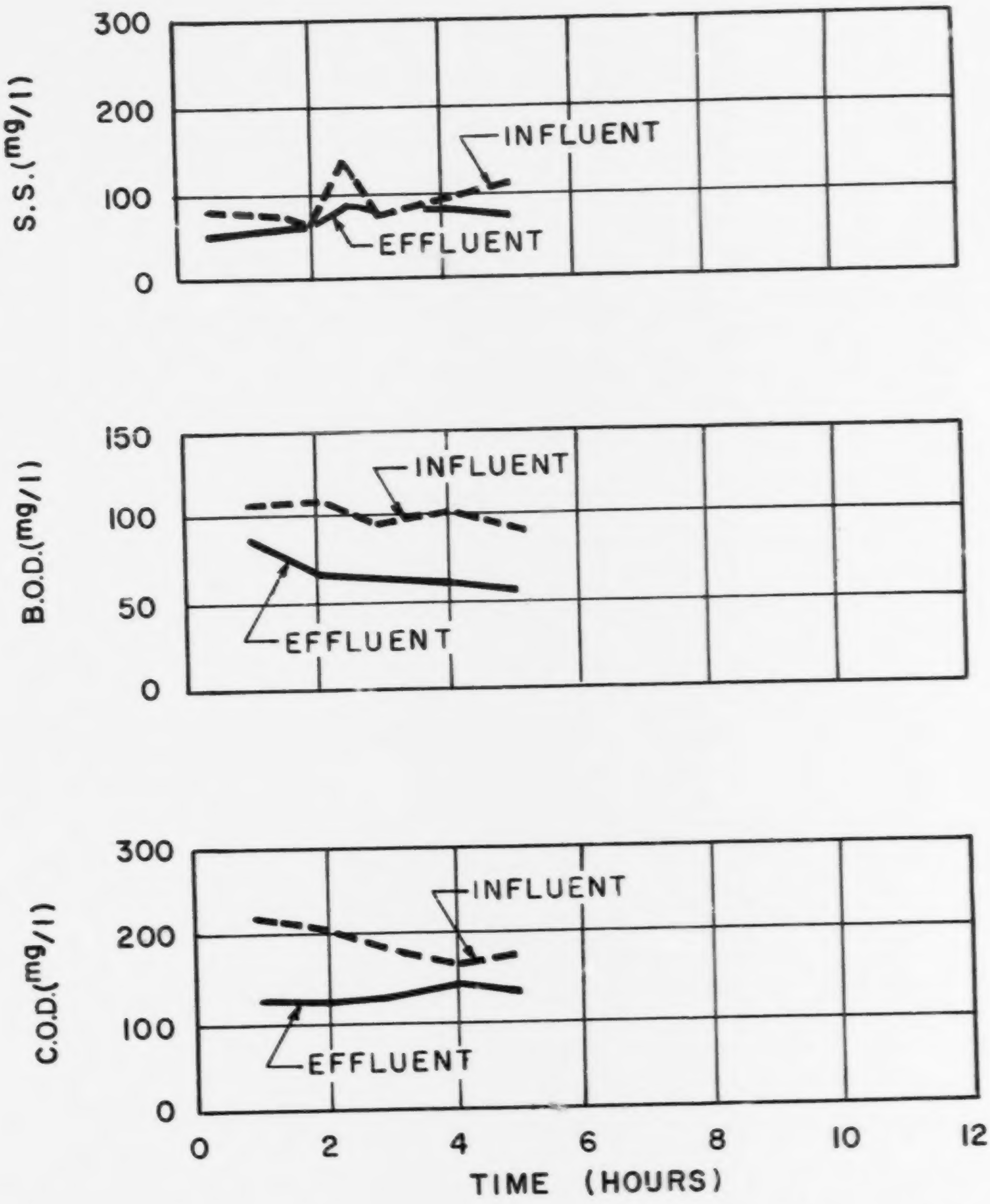
SCREEN 40 MESH. FILTER MEDIA 60 in. No. 3 ANTH./36 in. No. 612 SAND

DATE 10/6/70 FLUX RATE 10 gpm/ft$^2$

RUN No. 9SFIII

## COMBINED SEWER OVERFLOW FILTRATION TEST

FIGURE C24



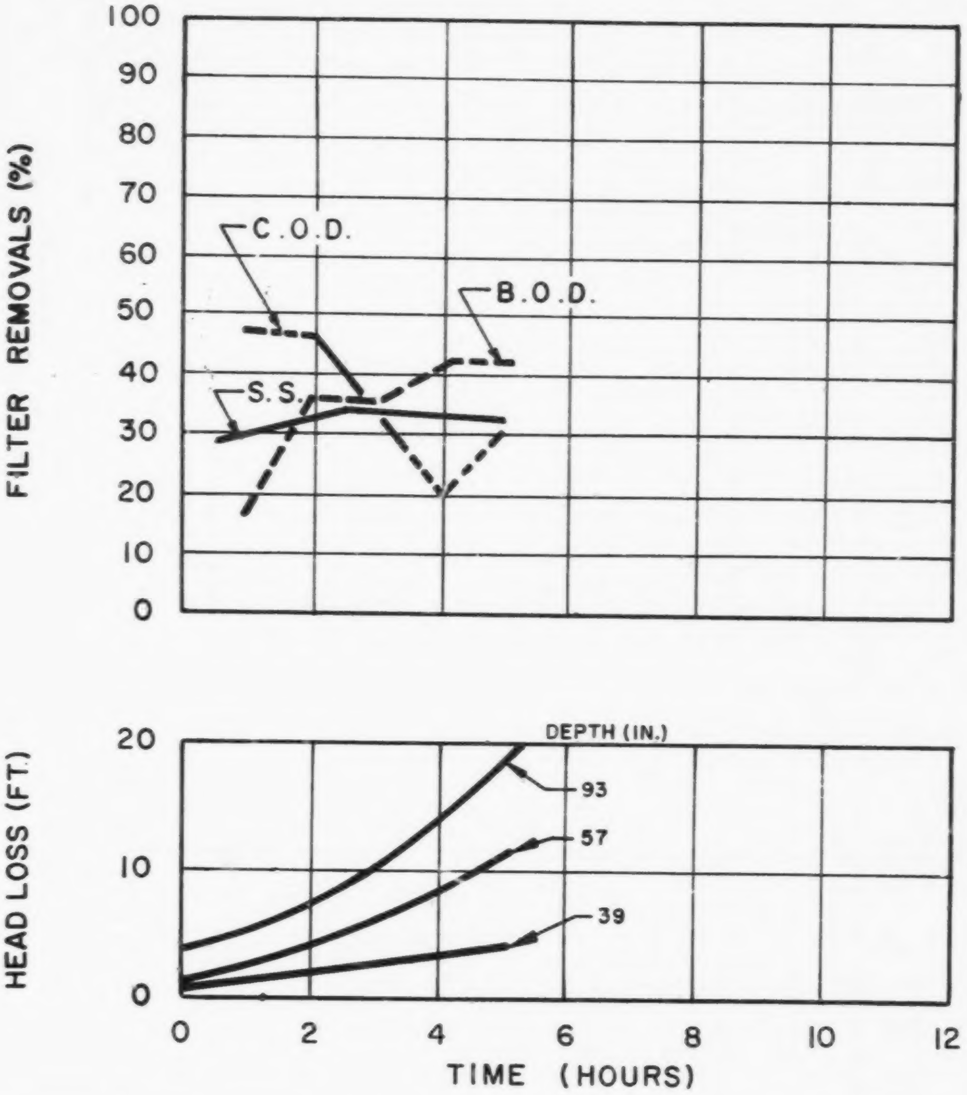
SCREEN 40 MESH. FILTER MEDIA 60 in. No. 3 ANTH./36 in. No. 612 SAND

DATE 10/6/70 FLUX RATE 40 $gpm/ft^2$

RUN No. 9ASFIII

COMBINED SEWER OVERFLOW FILTRATION TEST

FIGURE C25



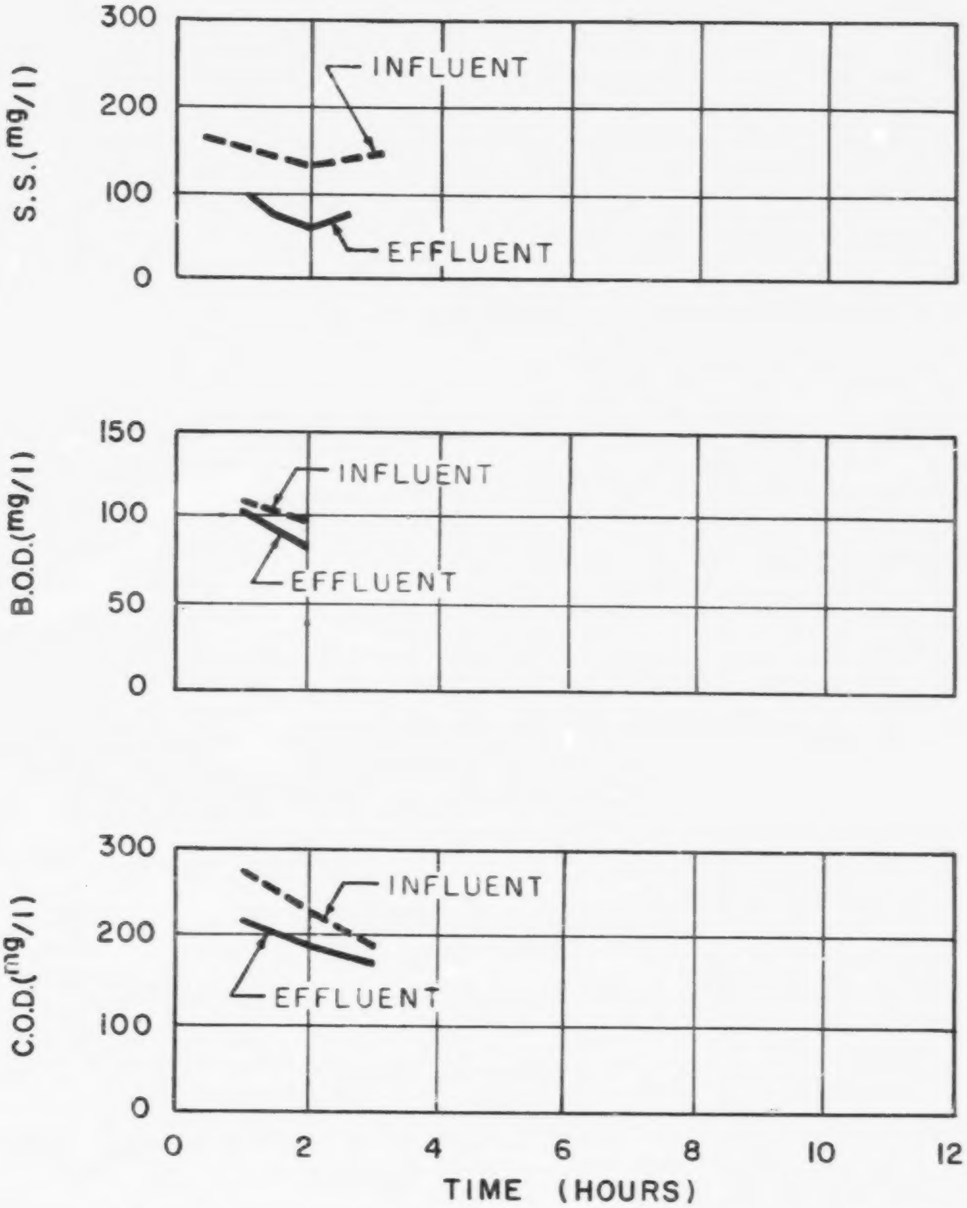
SCREEN 40 MESH. FILTER MEDIA. 60 in. No. 3 ANTH./ 36 in. No. 612 SAND

DATE 10/6/70 FLUX RATE 40 gpm/ft$^2$

RUN No. 9ASFIII

**COMBINED SEWER OVERFLOW FILTRATION TEST**

FIGURE C26



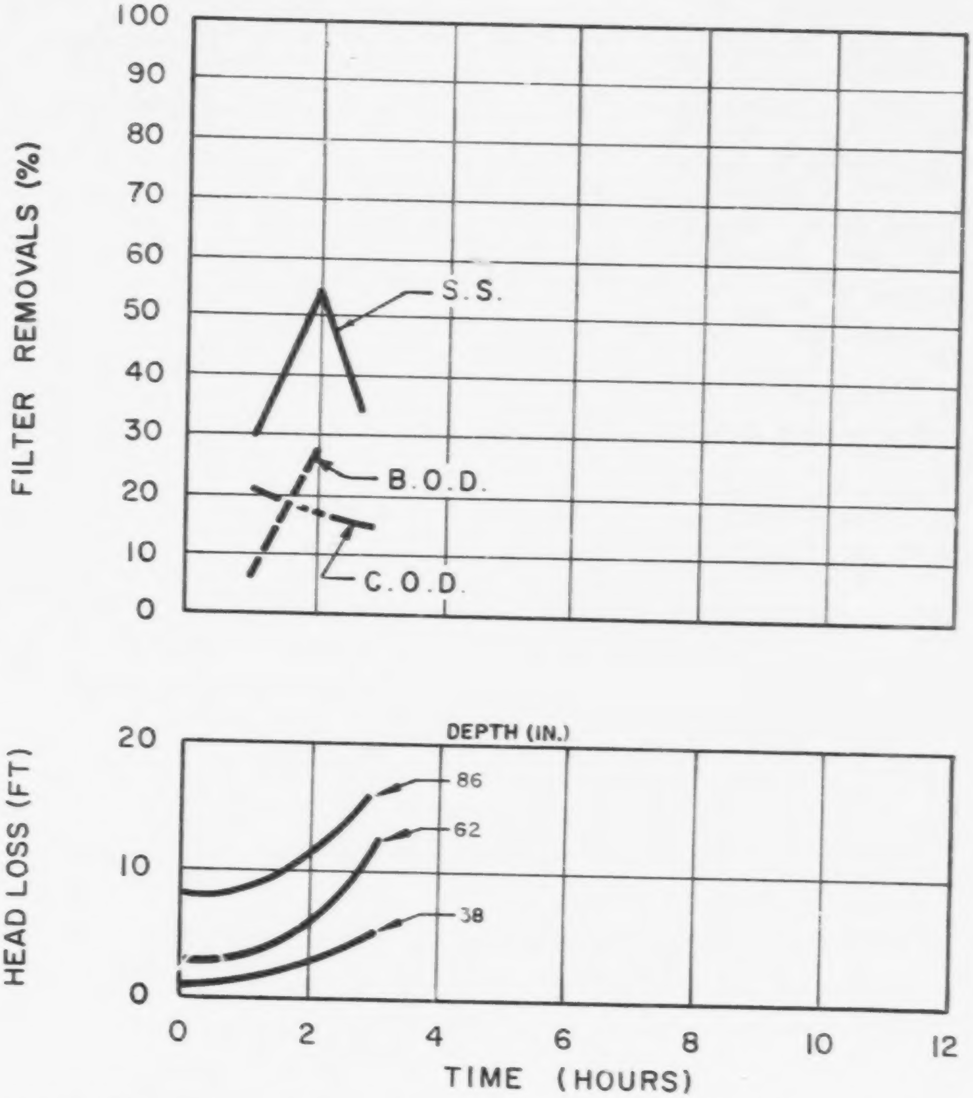
SCREEN 40 MESH. FILTER MEDIA 48 in. No. 3 ANTH./36 in. No. 612 SAND

DATE 10/12/70 FLUX RATE 32 gpm/ft$^2$

RUN No. 10SFI

**COMBINED SEWER OVERFLOW FILTRATION TEST**

FIGURE C27



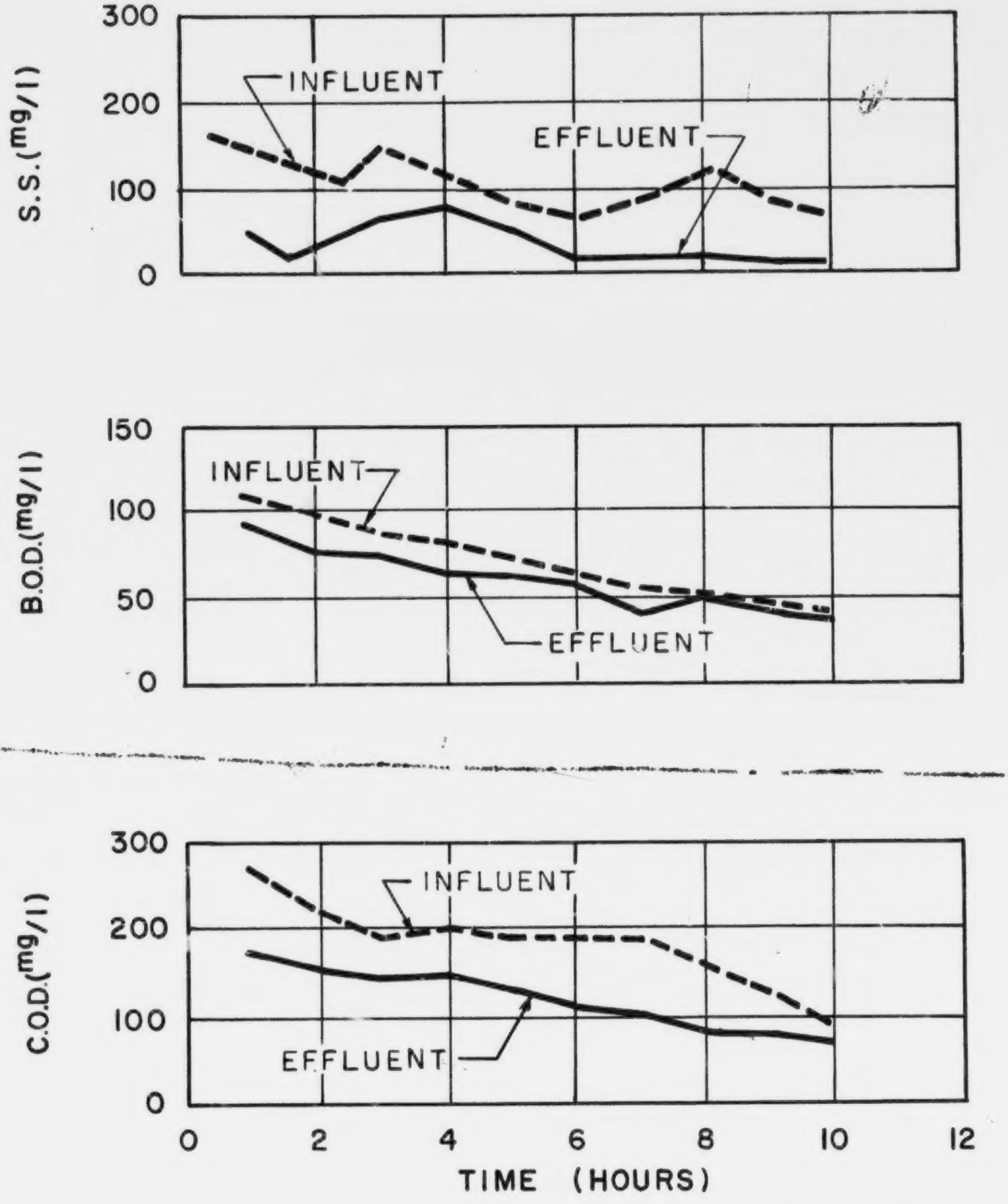
SCREEN 40 MESH. FILTER MEDIA 48 in. No. 3 ANTH./36 in. No. 612 SAND

DATE 10 / 12 / 70 FLUX RATE 32 gpm/ft$^2$

RUN No. 105FI

**COMBINED SEWER OVERFLOW FILTRATION TEST**

FIGURE C 28



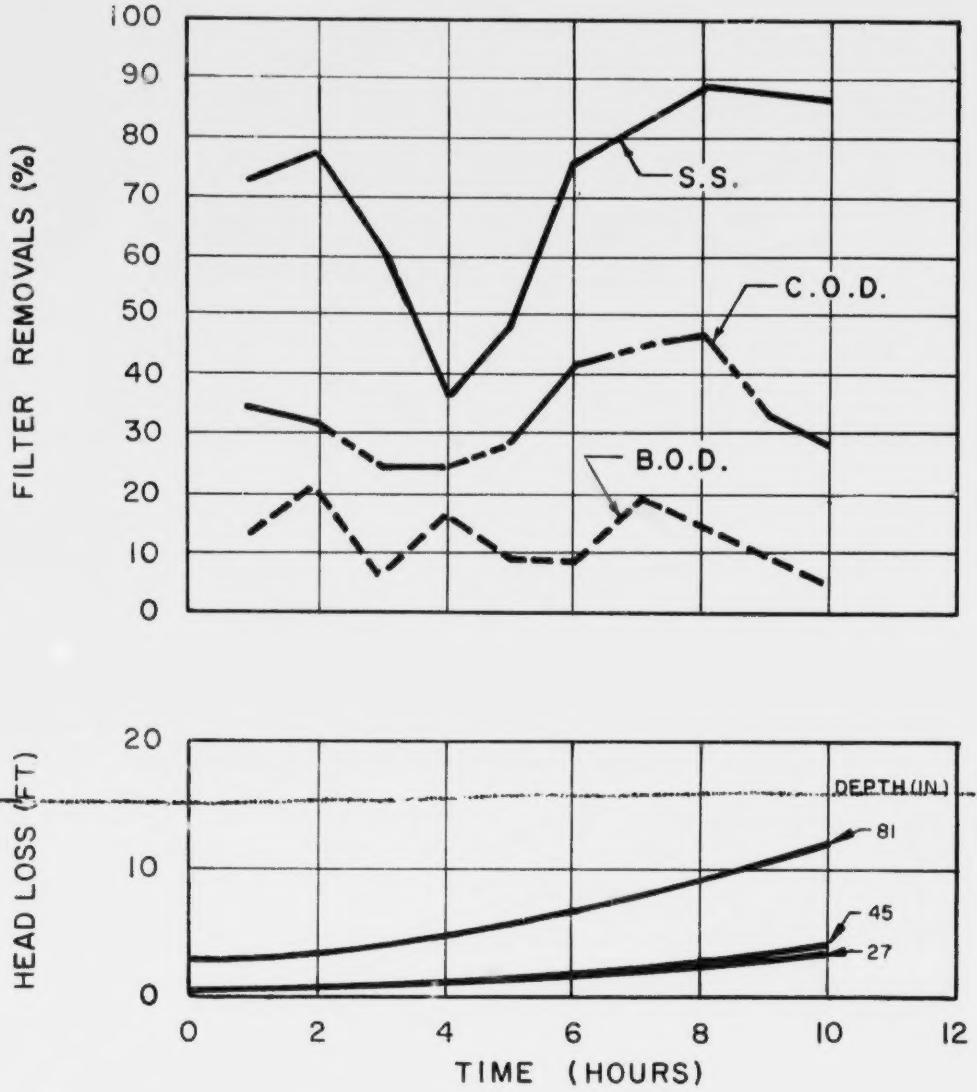
SCREEN 40 MESH. FILTER MEDIA 48 in. No. 3 ANTH./ 36 in. No. 612 SAND

DATE 10/12/70 FLUX RATE 16 gpm/ft$^2$

RUN No. 10SF11

**COMBINED SEWER OVERFLOW FILTRATION TEST**

FIGURE C29



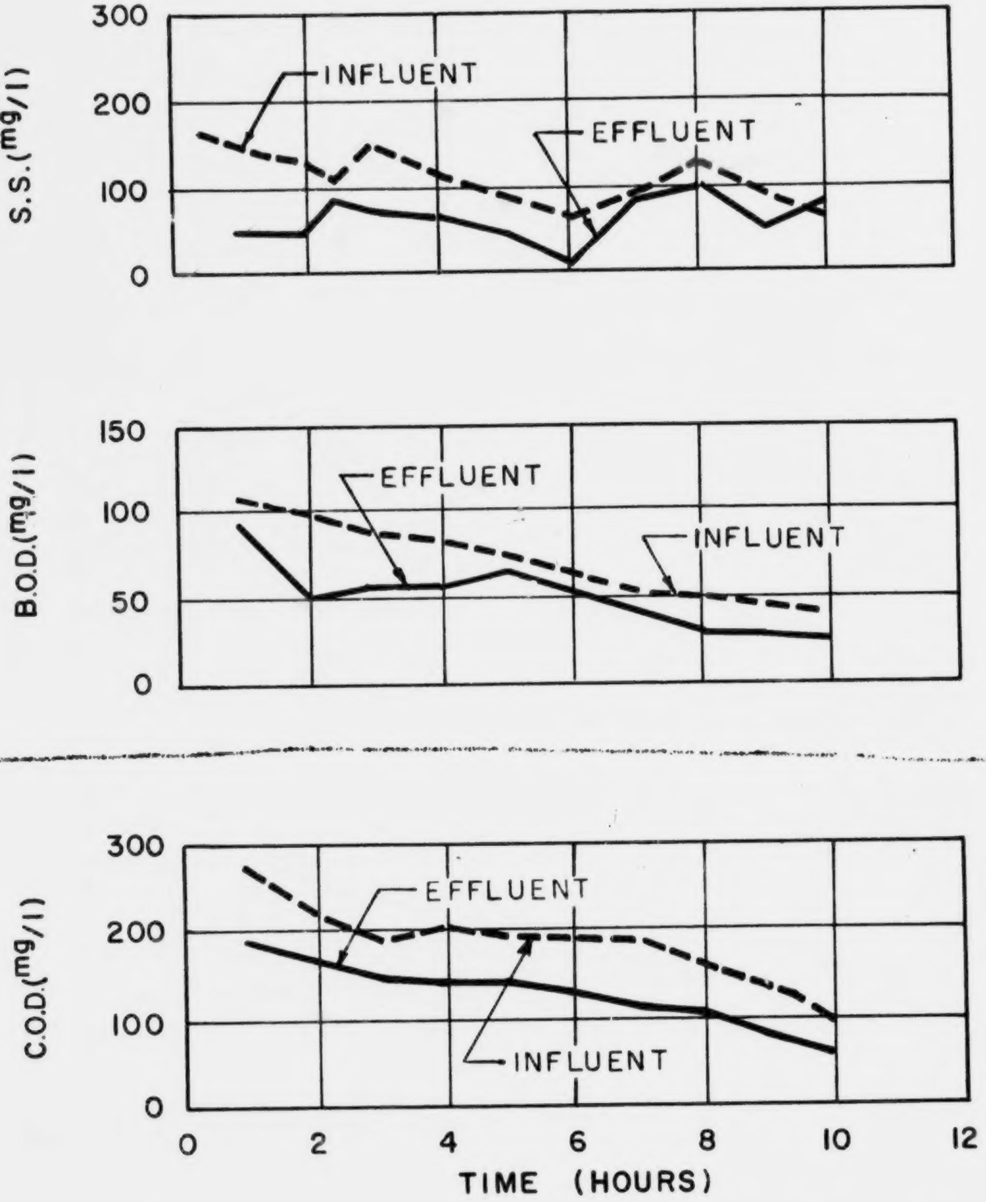
SCREEN 40 MESH. FILTER MEDIA 48 in. No. 3 ANTH./36 in. No. 612 SAND

DATE 10/12/70 FLUX RATE 16 gpm/ft²

RUN No. 10SFII

**COMBINED SEWER OVERFLOW FILTRATION TEST**

FIGURE C30



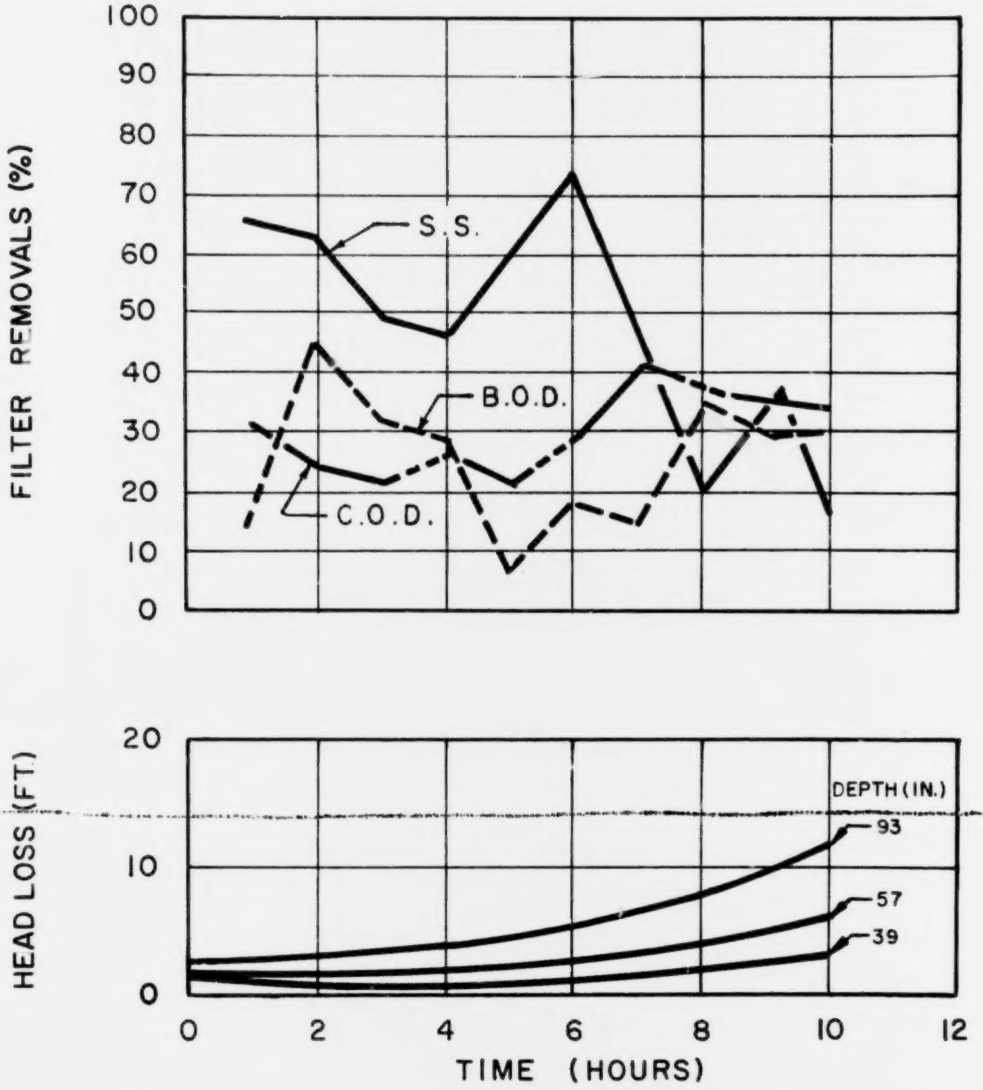
SCREEN 40 MESH. FILTER MEDIA 60 in. No. 3 ANTH./36 in. No. 612 SAND

DATE 10/12/70 FLUX RATE 24 gpm/ft$^2$

RUN No. 10SF111

**COMBINED SEWER OVERFLOW FILTRATION TEST**

**FIGURE C31**



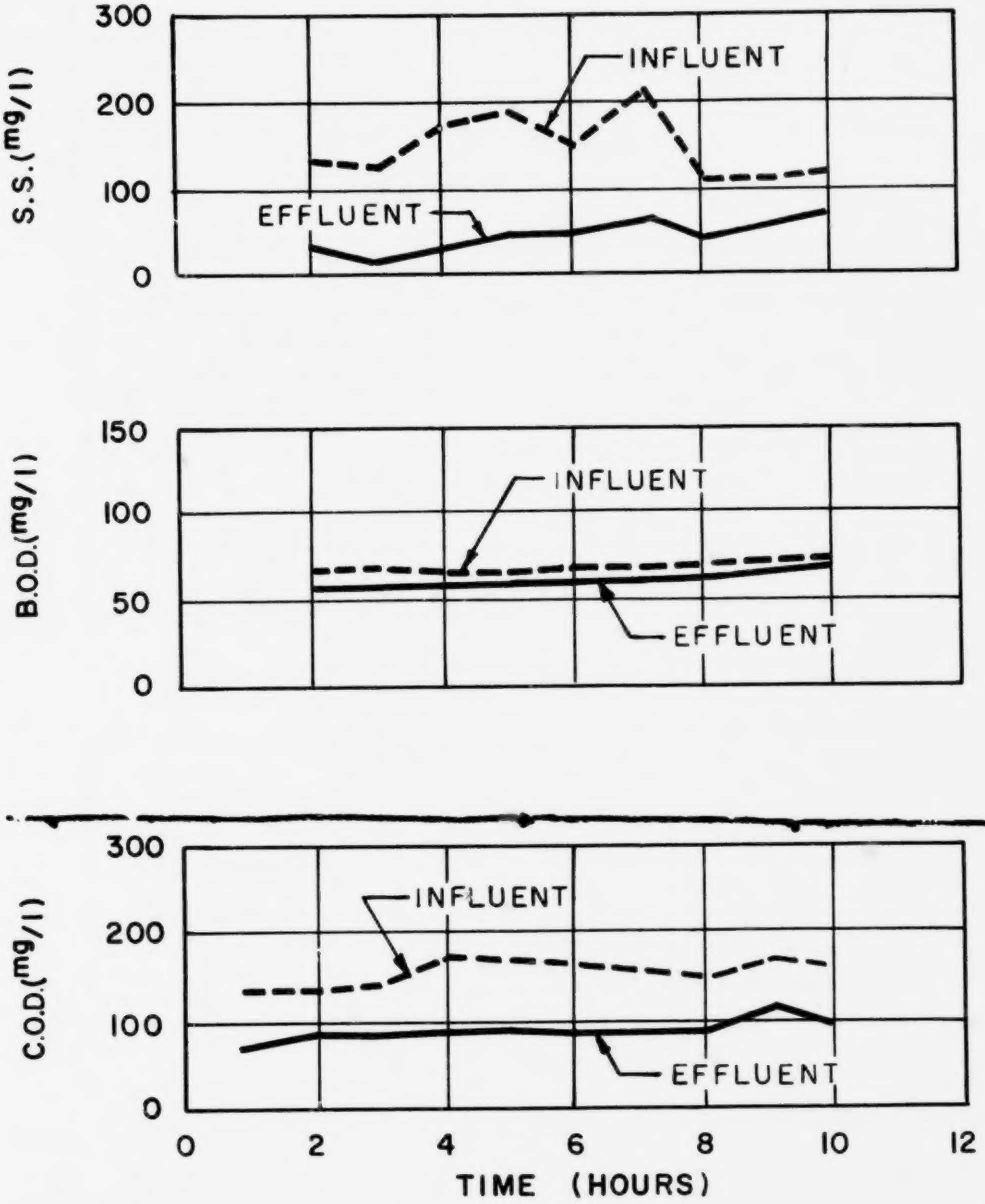
SCREEN 40 MESH. FILTER MEDIA 60 in. No. 3 ANTH./36 in. No. 620 SAND

DATE 10/12/70 FLUX RATE 24 gpm/ft$^2$

RUN No. 10SF111

**COMBINED SEWER OVERFLOW FILTRATION TEST**

FIGURE C32



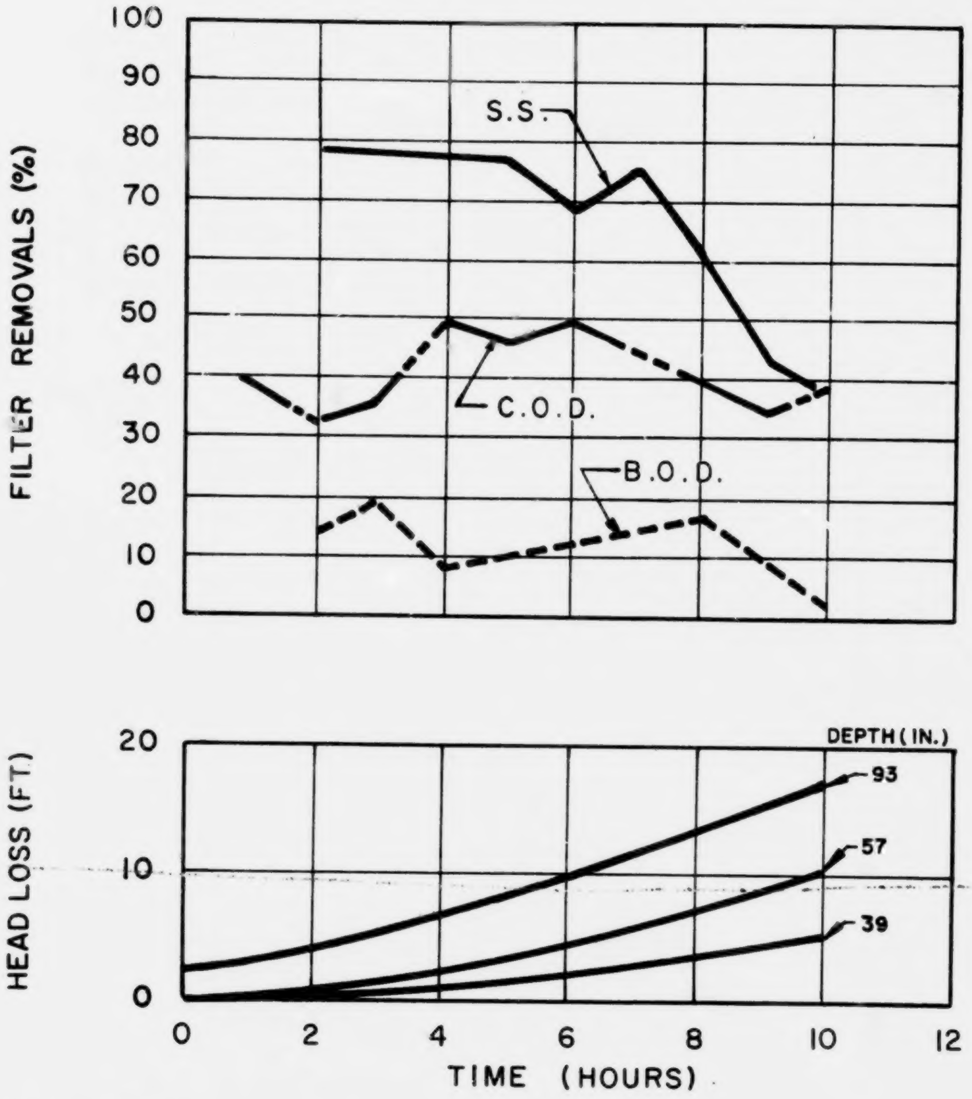
SCREEN 40 MESH. FILTER MEDIA 60 in. No. 3 ANTH./36 in. No. ____ SAND

DATE 10/13/70 FLUX RATE 24 gpm/ft$^2$ POLY. NALCO 671 0.5 mg/l

RUN No. 10ASFIII

**COMBINED SEWER OVERFLOW FILTRATION TEST**

FIGURE C33



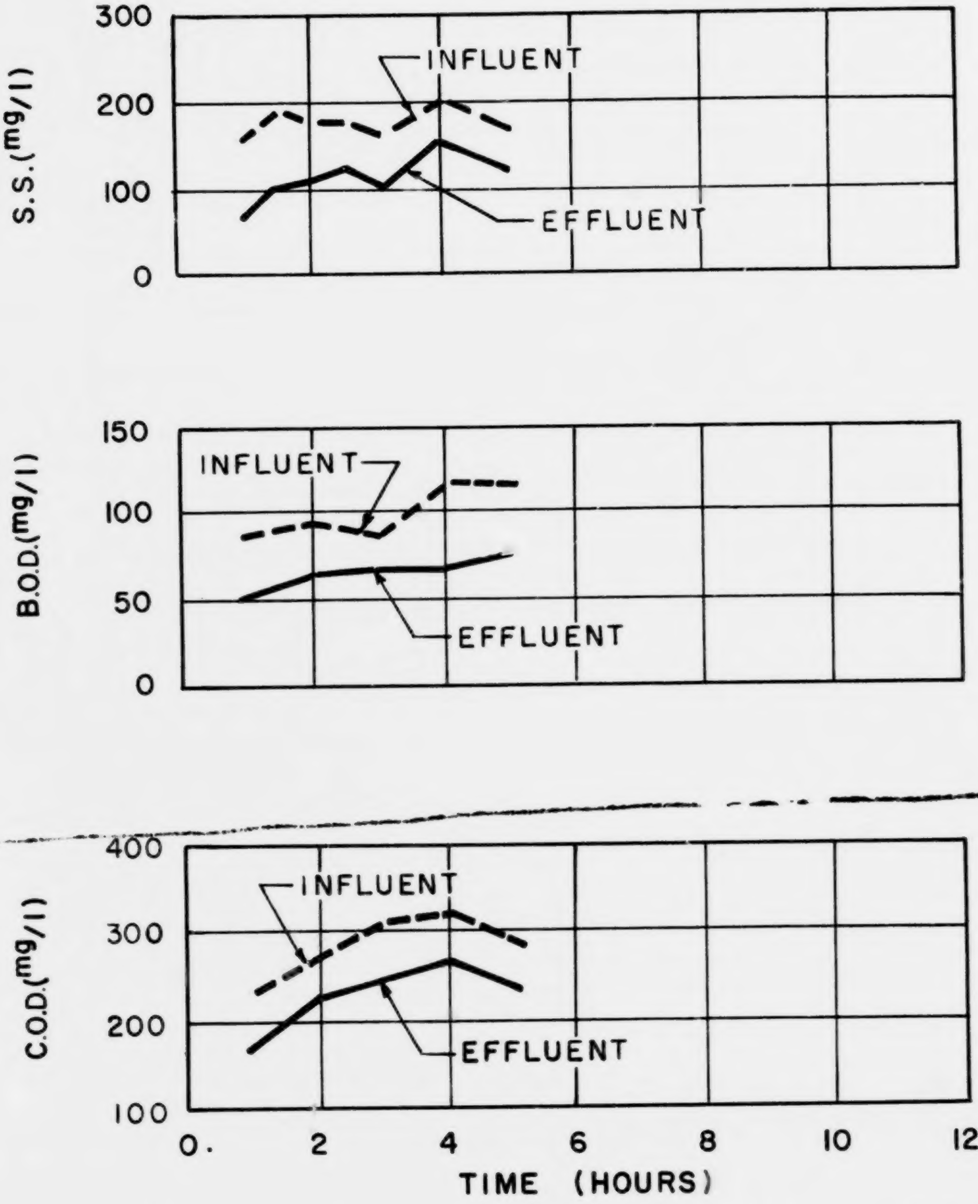
SCREEN 40 MESH. FILTER MEDIA 60 in. No. 3 ANTH./36 in. No. 612 SAND

DATE 10/13/70 FLUX RATE 24 gpm/ft$^2$ POLY. NALCO 671 0.5 mg/l

RUN No. 10ASFIII

## COMBINED SEWER OVERFLOW FILTRATION TEST

FIGURE C34



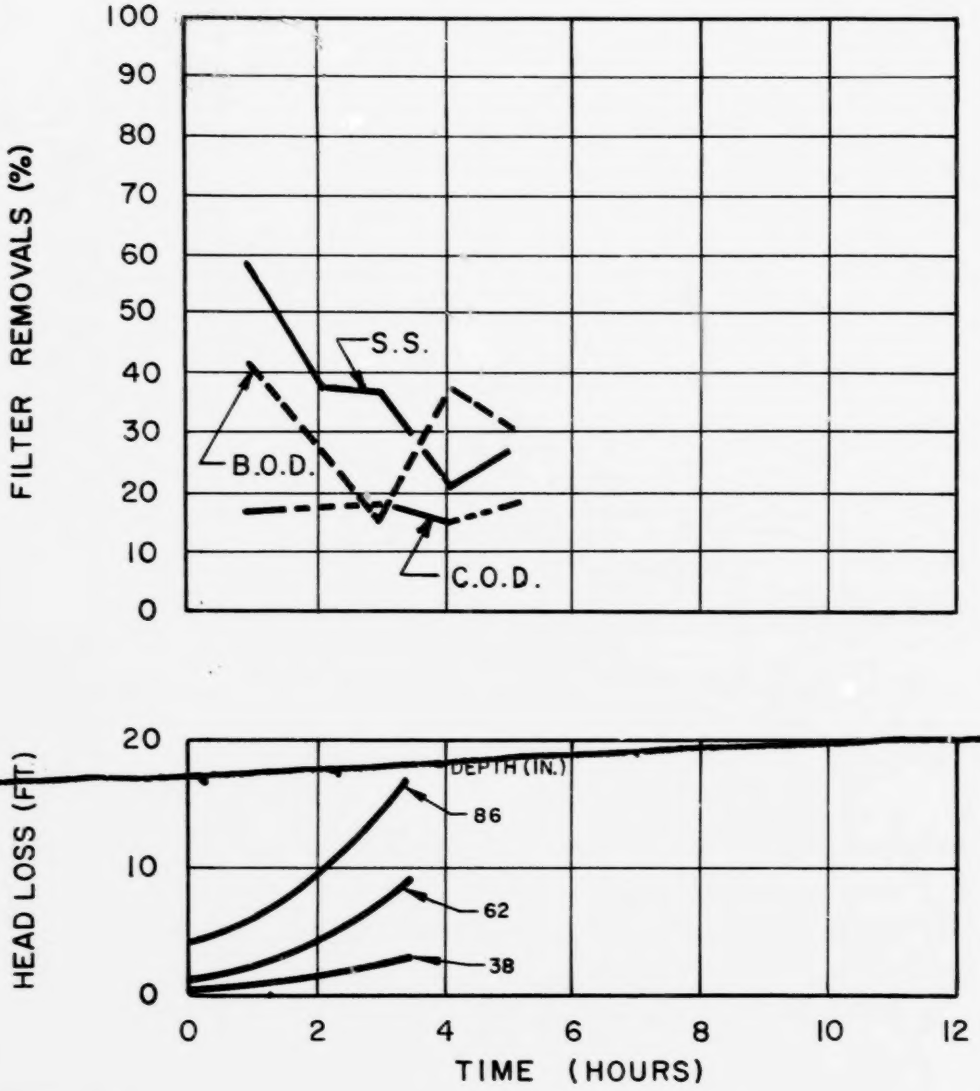
SCREEN 40 MESH. FILTER MEDIA 48 in. No. 3 ANTH./36 in. No. 612 SAND

DATE 10/21/70 FLUX RATE 32 $gpm/ft^2$ POLY. NALCO 671 0.5mg/l

RUN No. 11SF1

**COMBINED SEWER OVERFLOW FILTRATION TEST**

FIGURE C35



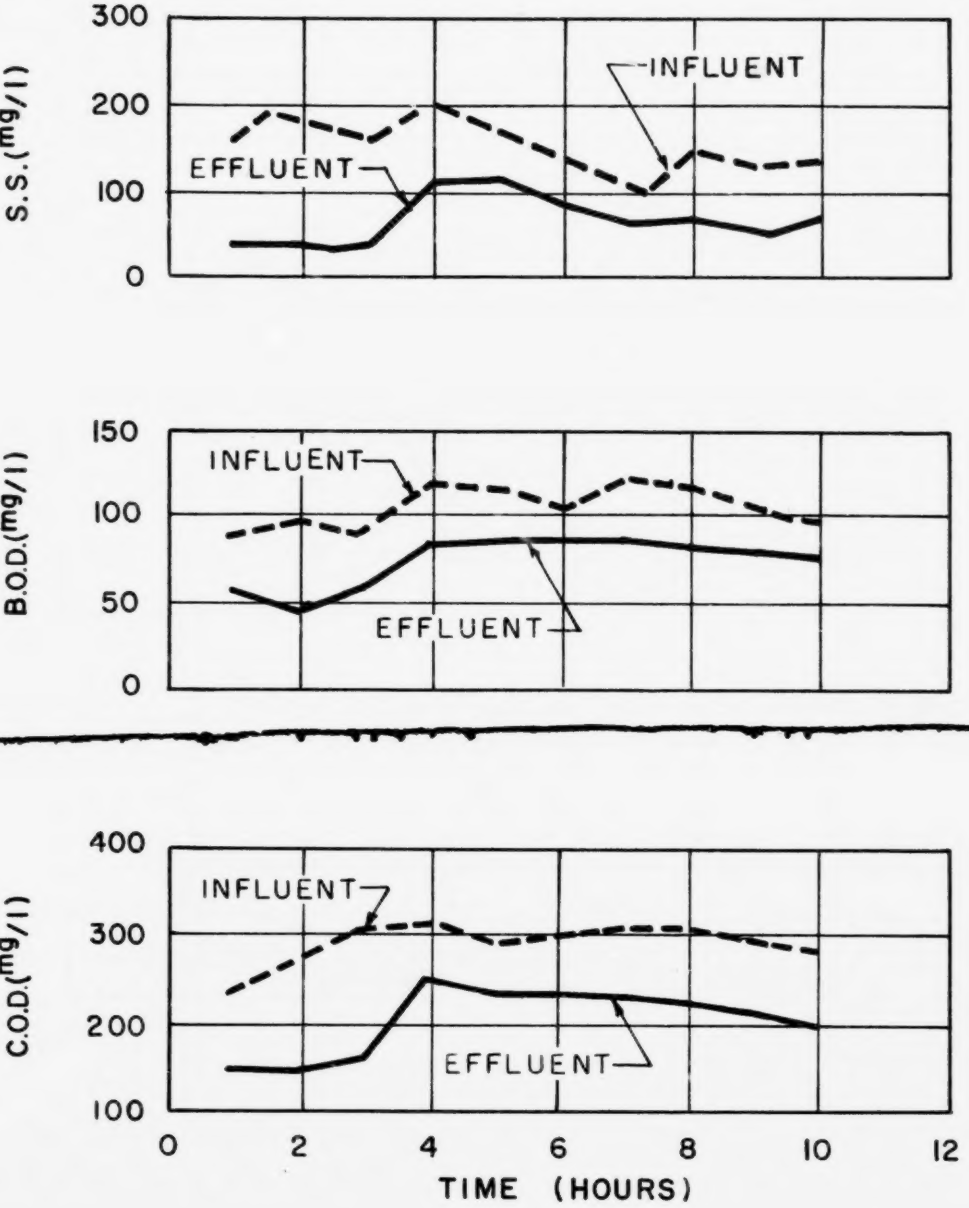
SCREEN 40 MESH. FILTER MEDIA 48 in. No. 3 ANTH./36 in. No. 612 SAND

DATE 10/21/70 FLUX RATE 32 gpm/ft$^2$ POLY. NALCO 671 0.5 mg/l

RUN No. 11SF1

**COMBINED SEWER OVERFLOW FILTRATION TEST**

FIGURE C36



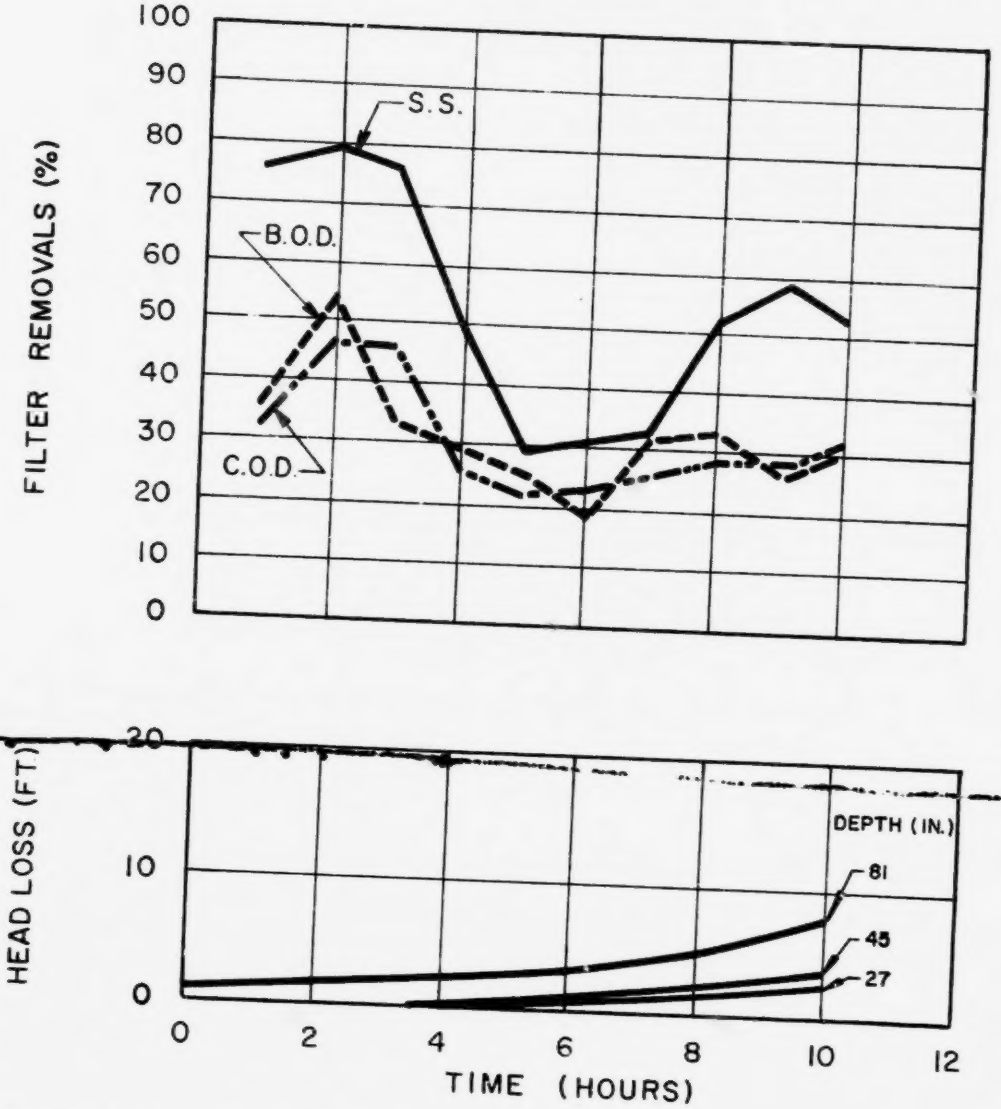
SCREEN 40 MESH. FILTER MEDIA 48 in. No. 3 ANTH./36 in. No. 612 SAND

DATE 10/21/70 FLUX RATE 16 gpm/ft$^2$ POLY. NALCO 671 2.0mg/l

RUN No. 11SF11

## COMBINED SEWER OVERFLOW FILTRATION TEST

FIGURE C37



SCREEN 40 MESH. FILTER MEDIA 48 in. No. 3 ANTH./36 in. No. 612 SAND

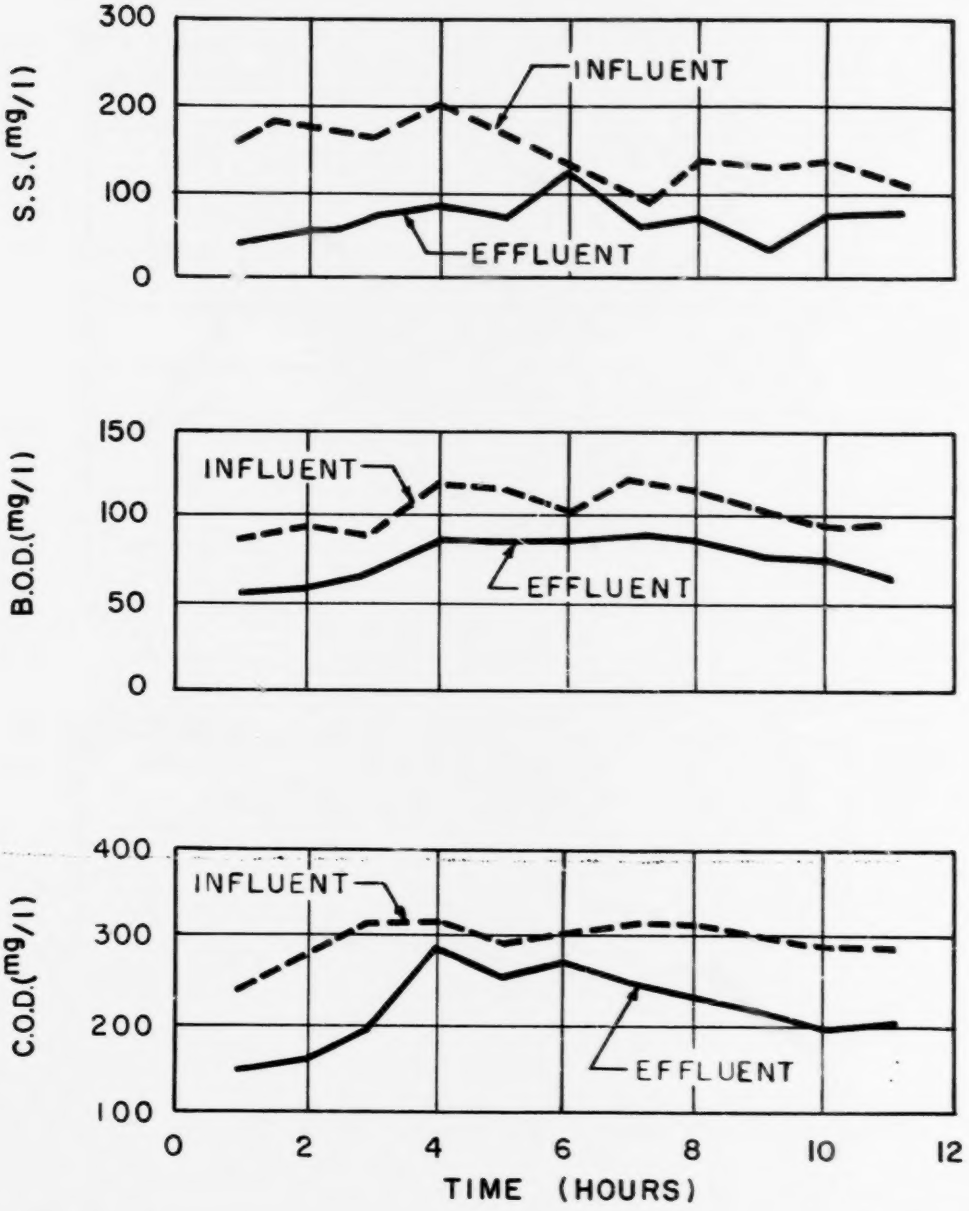
DATE 10/21/70 FLUX RATE 16 gpm/ft$^2$

POLY. NALCO 671
2.0mg/l

RUN No. 11SFII

## COMBINED SEWER OVERFLOW FILTRATION TEST

FIGURE C 38



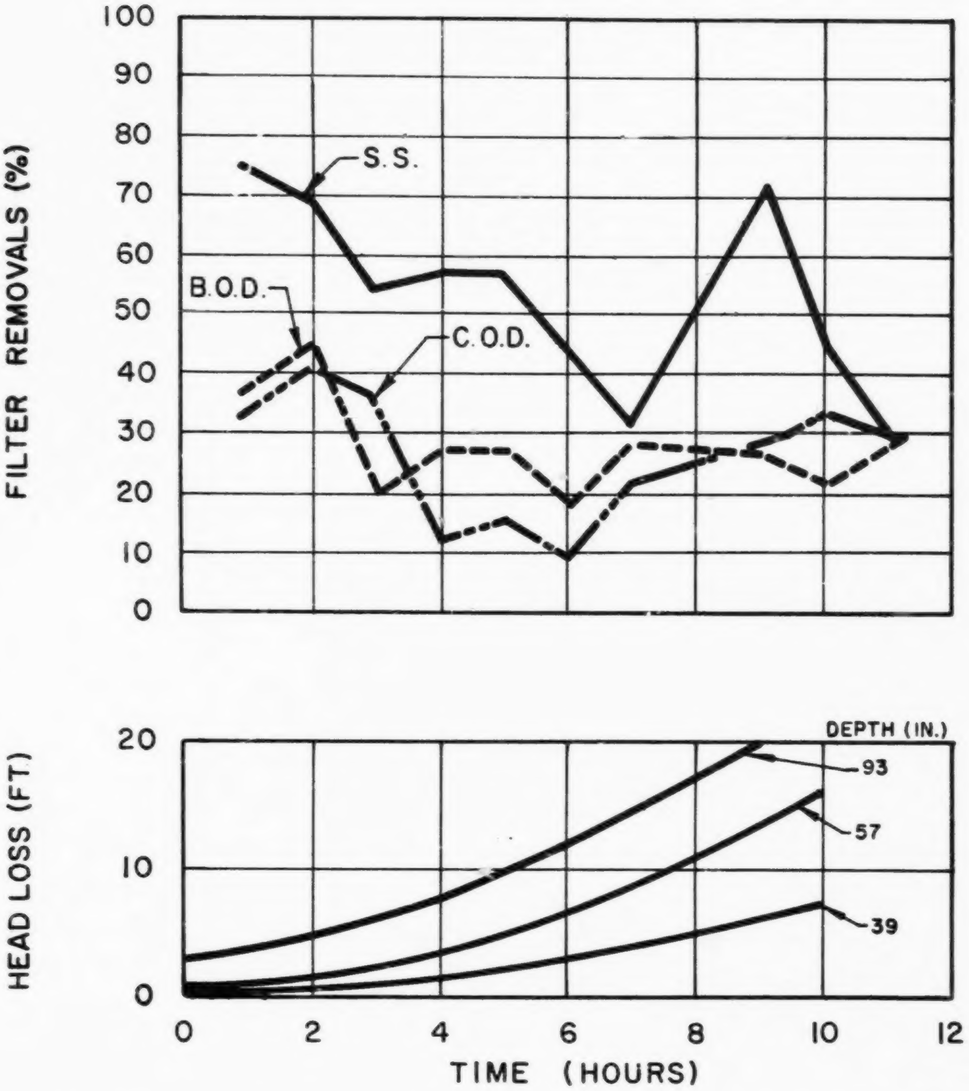
SCREEN 40 MESH. FILTER MEDIA 60 in. No. 3 ANTH./36 in. No. 612 SAND

DATE 10/21/70 FLUX RATE 24 gpm/ft$^2$ POLY. NALCO 671 2.0mg/l

RUN No. 11SFIII

COMBINED SEWER OVERFLOW FILTRATION TEST

FIGURE C39



SCREEN 40 MESH. FILTER MEDIA 60 in. No. 3 ANTH./ 36 in. No. 612 SAND

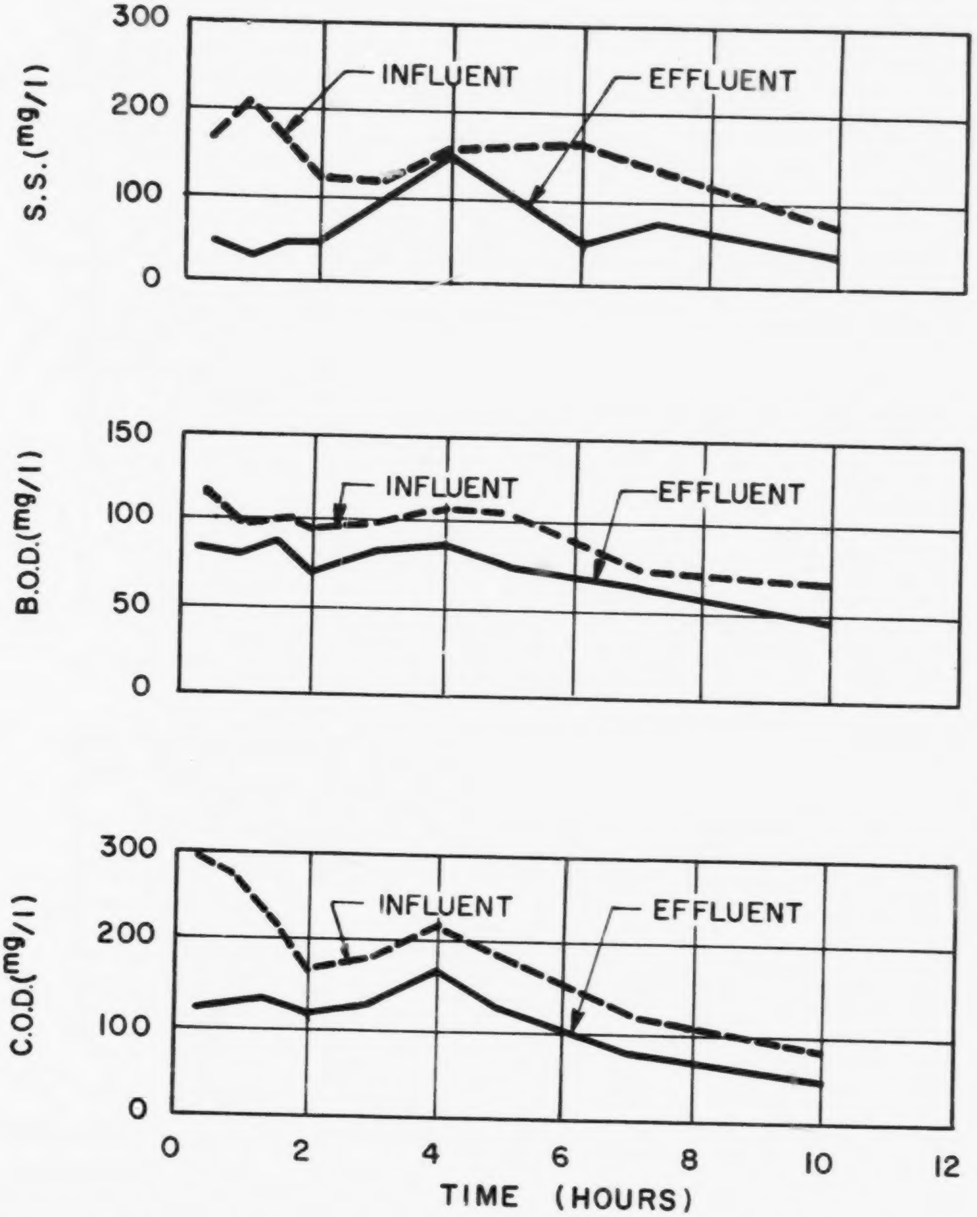
DATE 10/21/70 FLUX RATE 24 gpm/ft$^2$ POLY. NALCO 671

2.0mg/l

RUN No. 11SFIII

**COMBINED SEWER OVERFLOW FILTRATION TEST**

**FIGURE C 40**



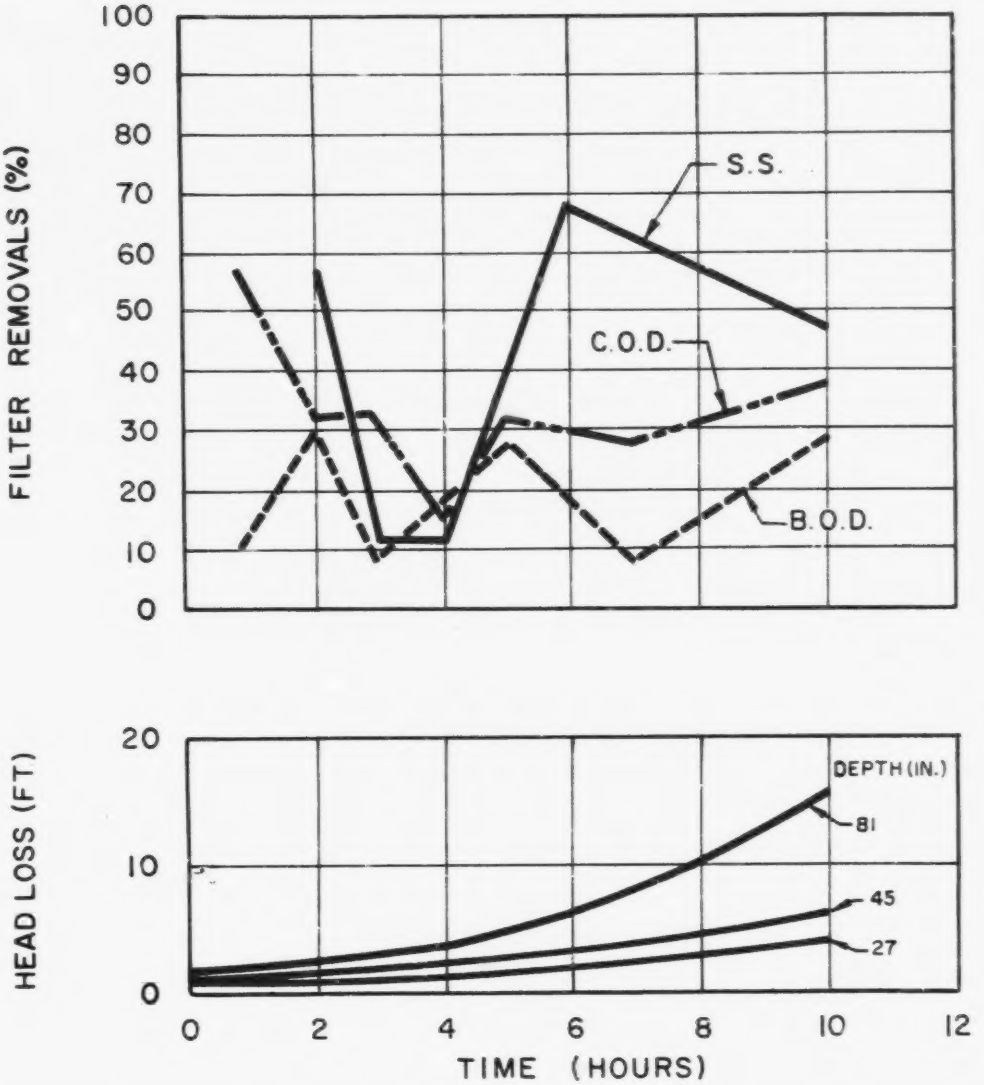
SCREEN 40 MESH. FILTER MEDIA 48 in. No. 3 ANTH. / 36 in. No. 612 SAND

DATE 11/2/70 FLUX RATE 24 gpm/ft$^2$ POLY. NALCO 671

RUN No. 13SFII 1.5 mg/l

COMBINED SEWER OVERFLOW FILTRATION TEST

FIGURE C 41



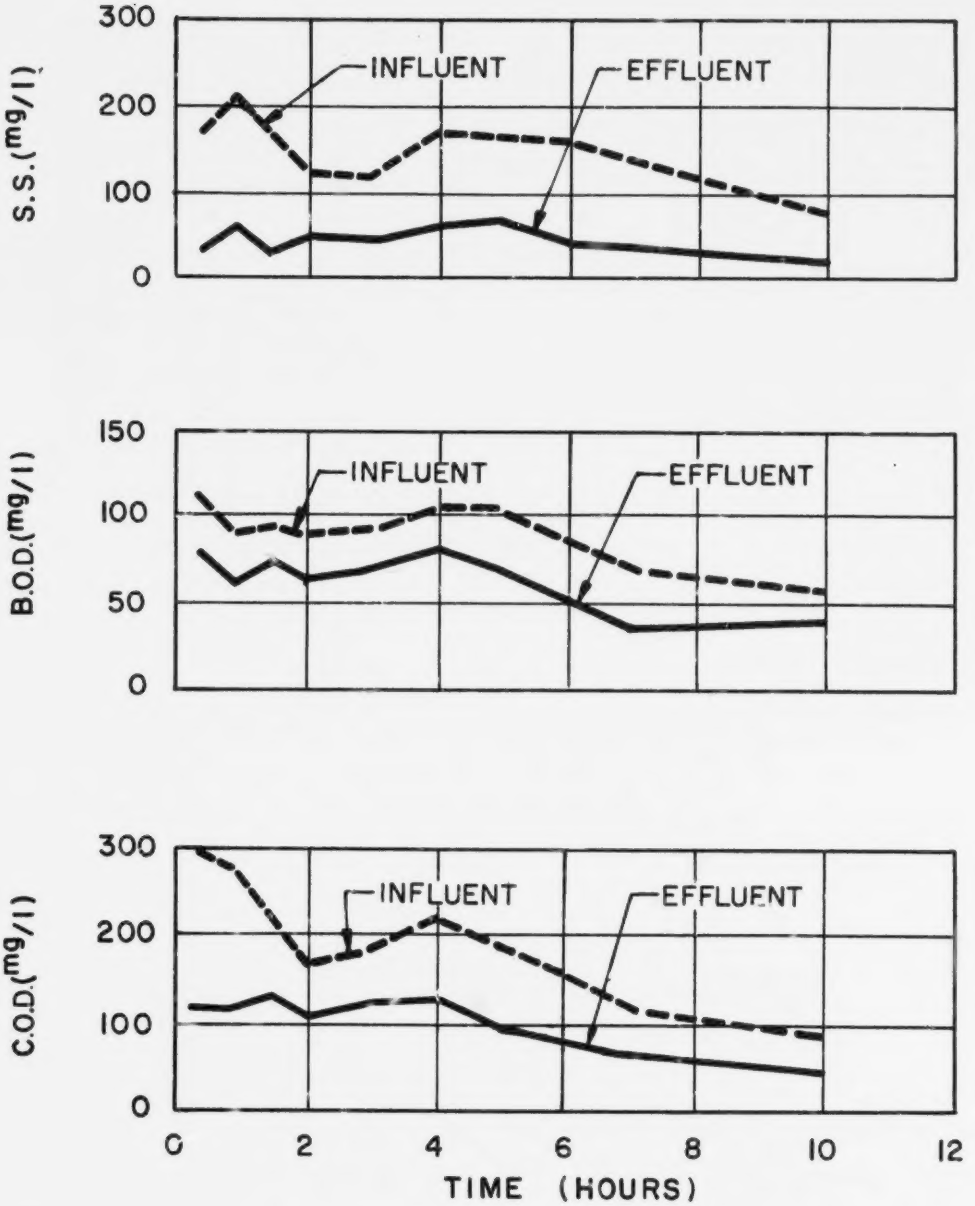
SCREEN 40 MESH. FILTER MEDIA 48 in. No. 3 ANTH./36 in. No. 612 SAND

DATE 11/2/70 FLUX RATE 24 gpm/ft$^2$ POLY. NALCO 671 1.5mg/l

RUN No. 13SFII

**COMBINED SEWER OVERFLOW FILTRATION TEST**

FIGURE C 42



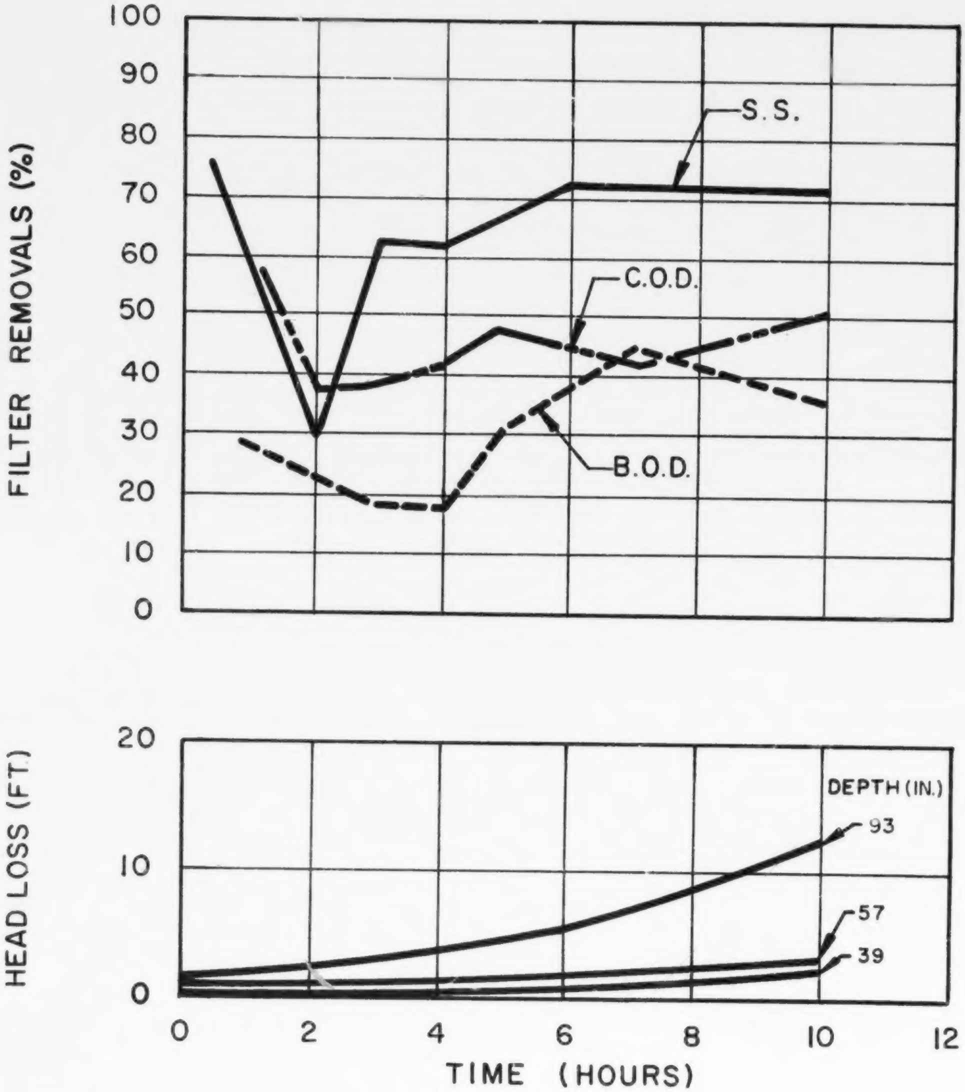
SCREEN 40 MESH. FILTER MEDIA 48 in. No. 3 ANTH. / 36 in. No. 612 SAND

DATE 11/2/70 FLUX RATE 16 gpm/ft$^2$ POLY. NALCO 671 1.5mg/l

RUN No. 13 SFIII

**COMBINED SEWER OVERFLOW FILTRATION TEST**

**FIGURE C 43**



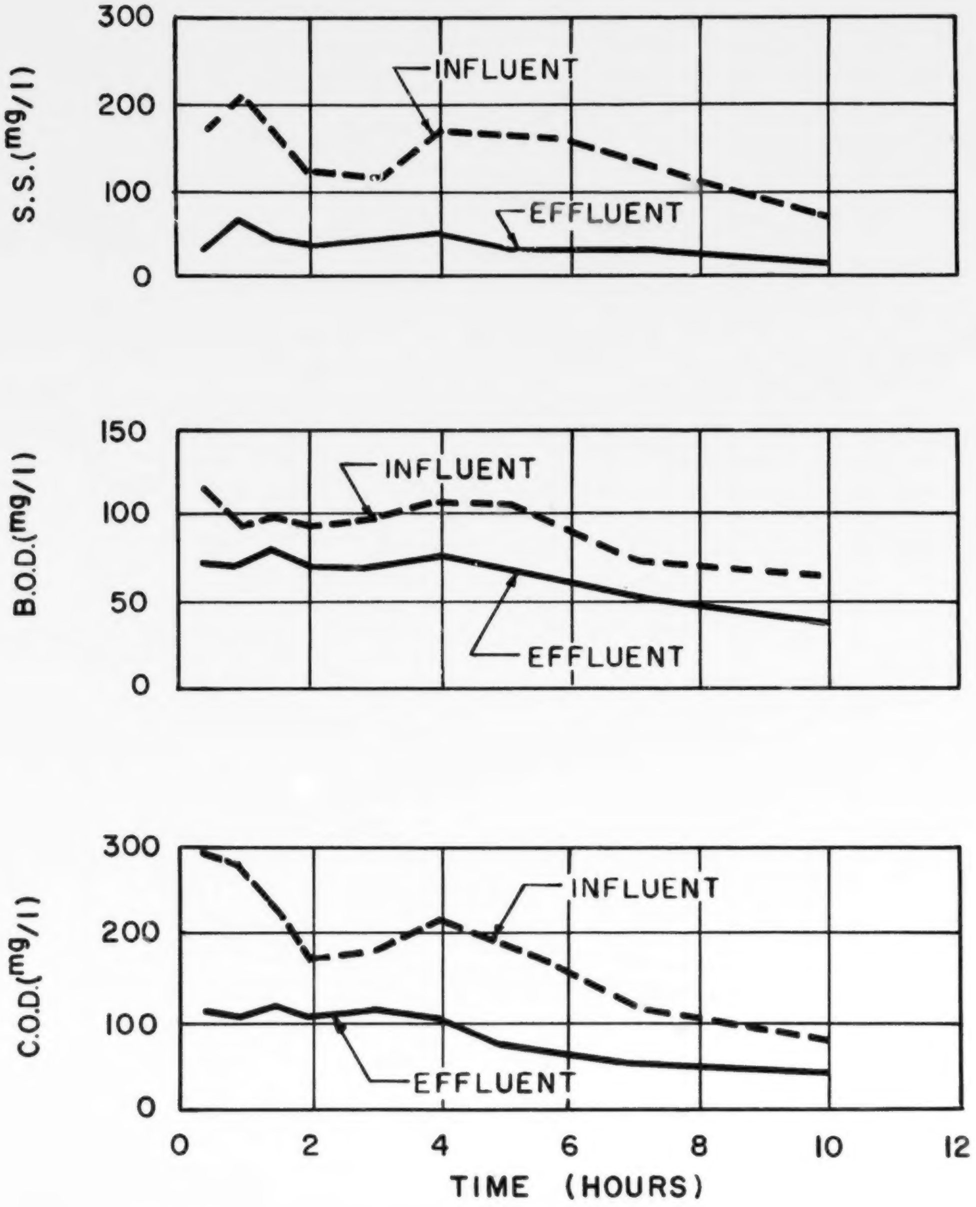
SCREEN 40 MESH. FILTER MEDIA 48 in. No. 3 ANTH./ 36 in. No. 612 SAND

DATE 11/2/70 FLUX RATE 16 gpm/ft² POLY. NALCO 671 1.5 mg/l

RUN No. 13SFIII

COMBINED SEWER OVERFLOW FILTRATION TEST

FIGURE C 44



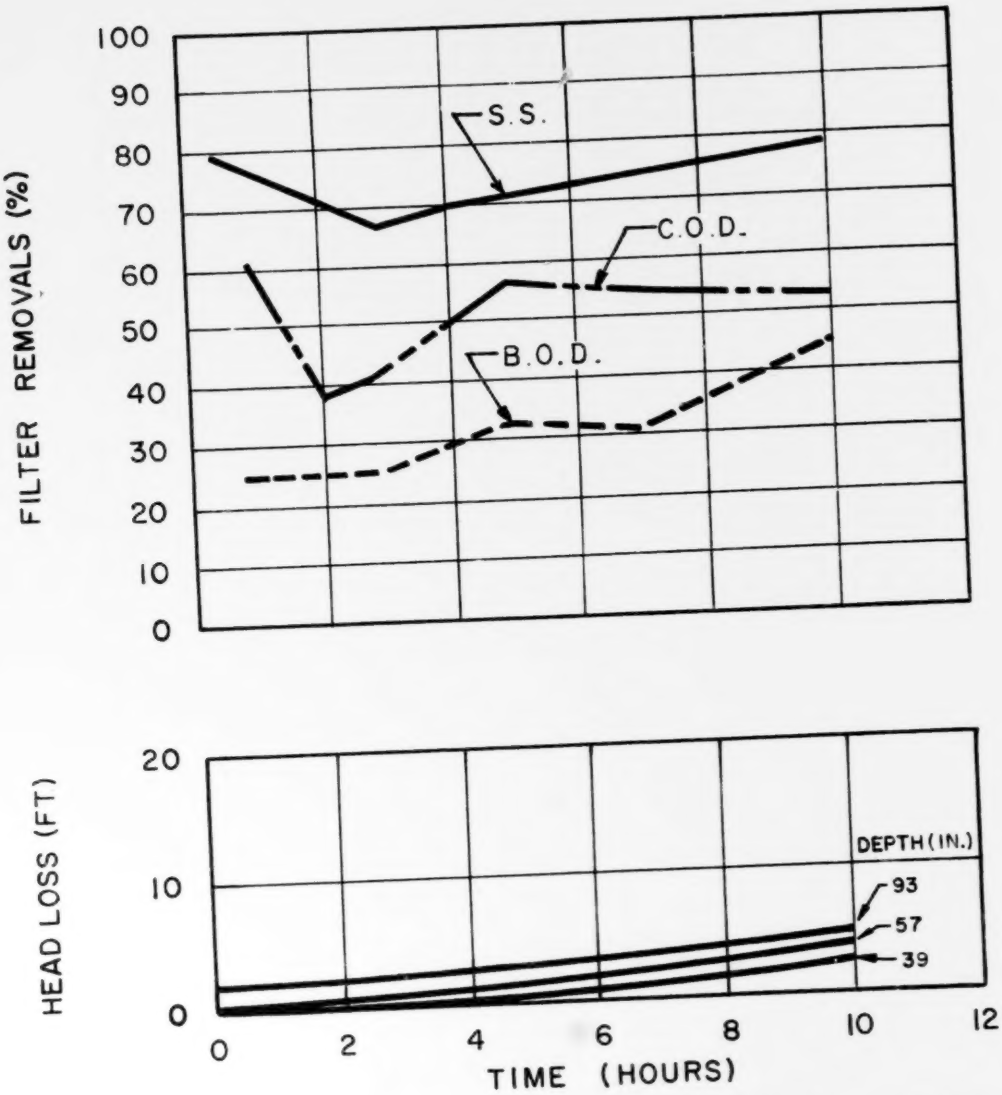
SCREEN 40 MESH. FILTER MEDIA 48 in. No. 3 ANTH./36 in. No. 612 SAND

DATE 11/2/70 FLUX RATE 10 gpm/ft$^2$ POLY. NALCO 671 1.5mg/l

RUN No. 13SFIV

**COMBINED SEWER OVERFLOW FILTRATION TEST**

**FIGURE C45**



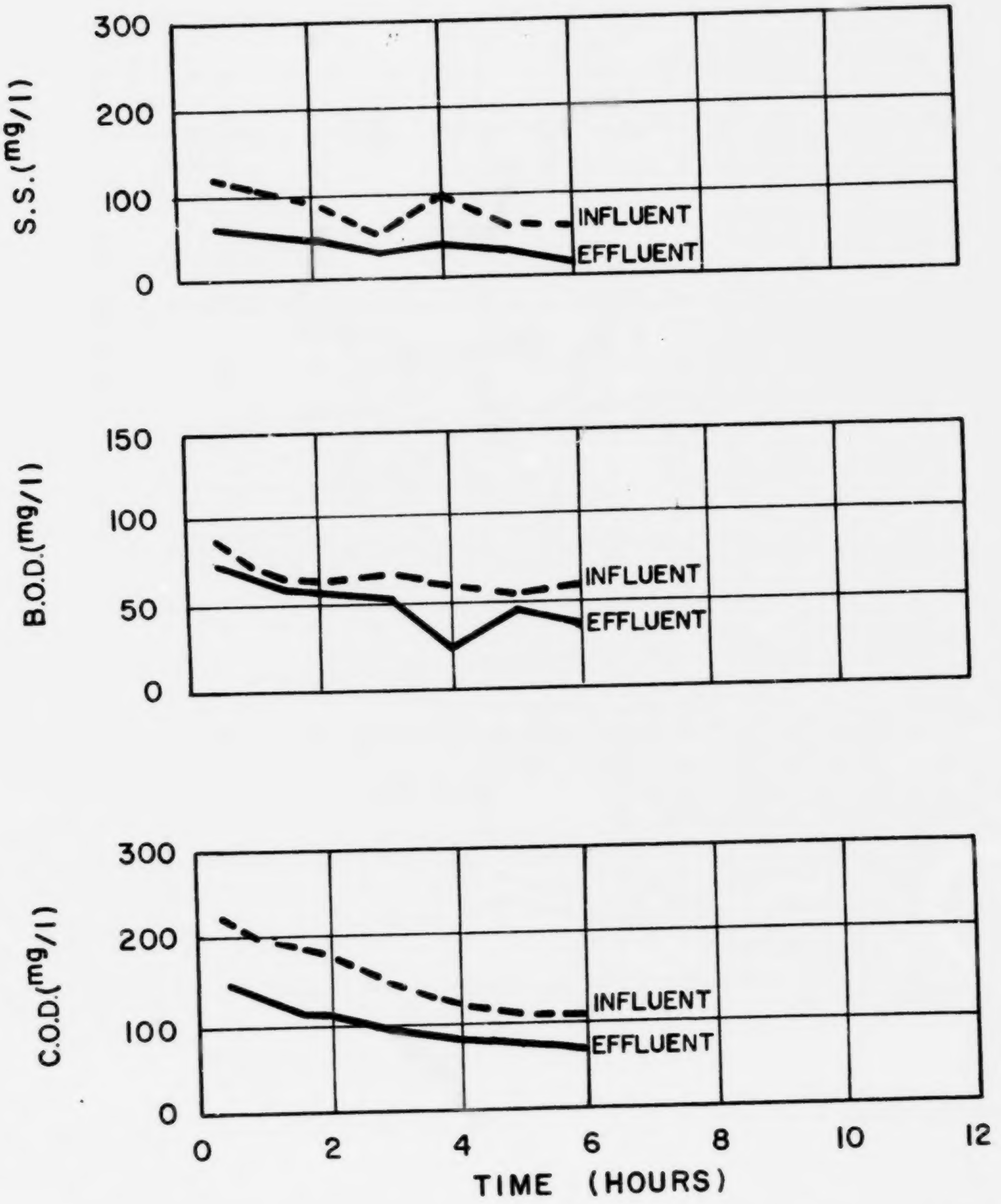
SCREEN 40 MESH. FILTER MEDIA 48 in. No. 3 ANTH./36 in. No. 612 SAND

DATE 11/2/70 FLUX RATE 10 gpm/ft² POLY. NALCO 671 1.5mg/l

RUN No. 13SFIV

COMBINED SEWER OVERFLOW FILTRATION TEST

FIGURE C46



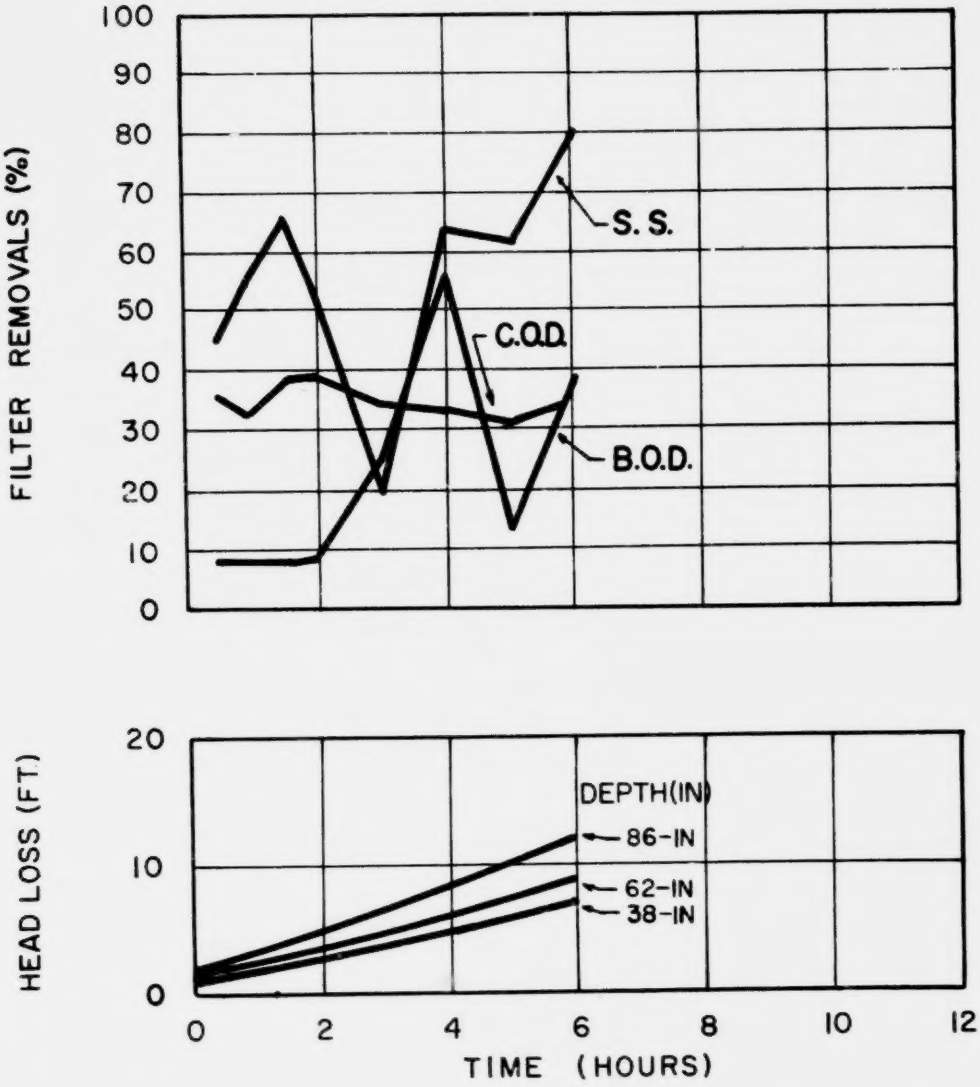
SCREEN 40 MESH. FILTER MEDIA 42 in. No. 3 ANTH./36 in. No. 612 SAND

DATE 11/14/70 FLUX RATE 16 gpm/ft$^2$ POLY. NALCO 671 0.5 mg/l

RUN No. 14SFI

## COMBINED SEWER OVERFLOW FILTRATION TEST

FIGURE C47



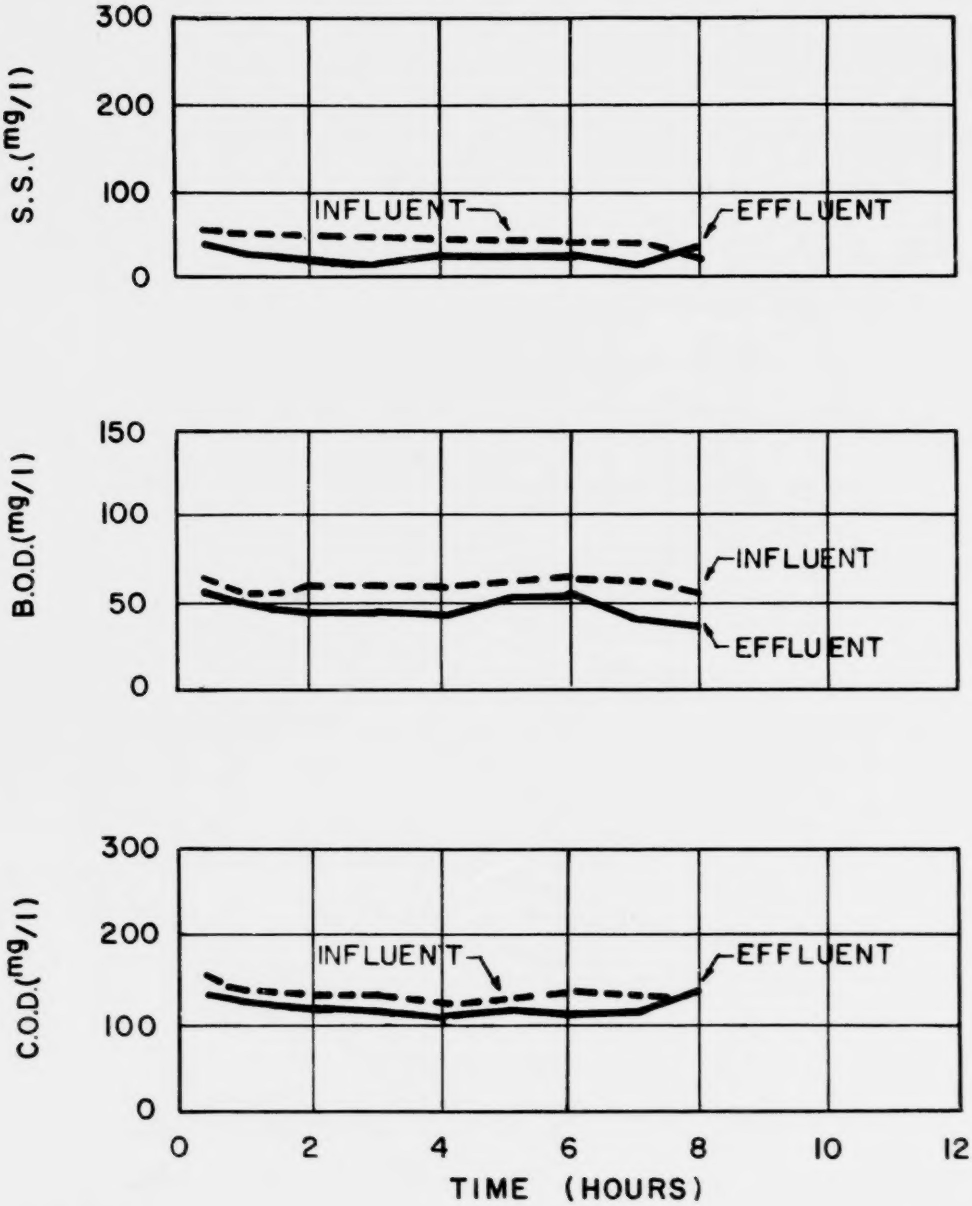
SCREEN 40 MESH. FILTER MEDIA 42 in. No. 3 ANTH./36 in. No. 612 SANC

DATE 11/14/70 FLUX RATE 16 gpm/ft$^2$ POLY. NALCO 671 0.5mg/l

RUN No. 14SFI

COMBINED SEWER OVERFLOW FILTRATION TEST

FIGURE C 48



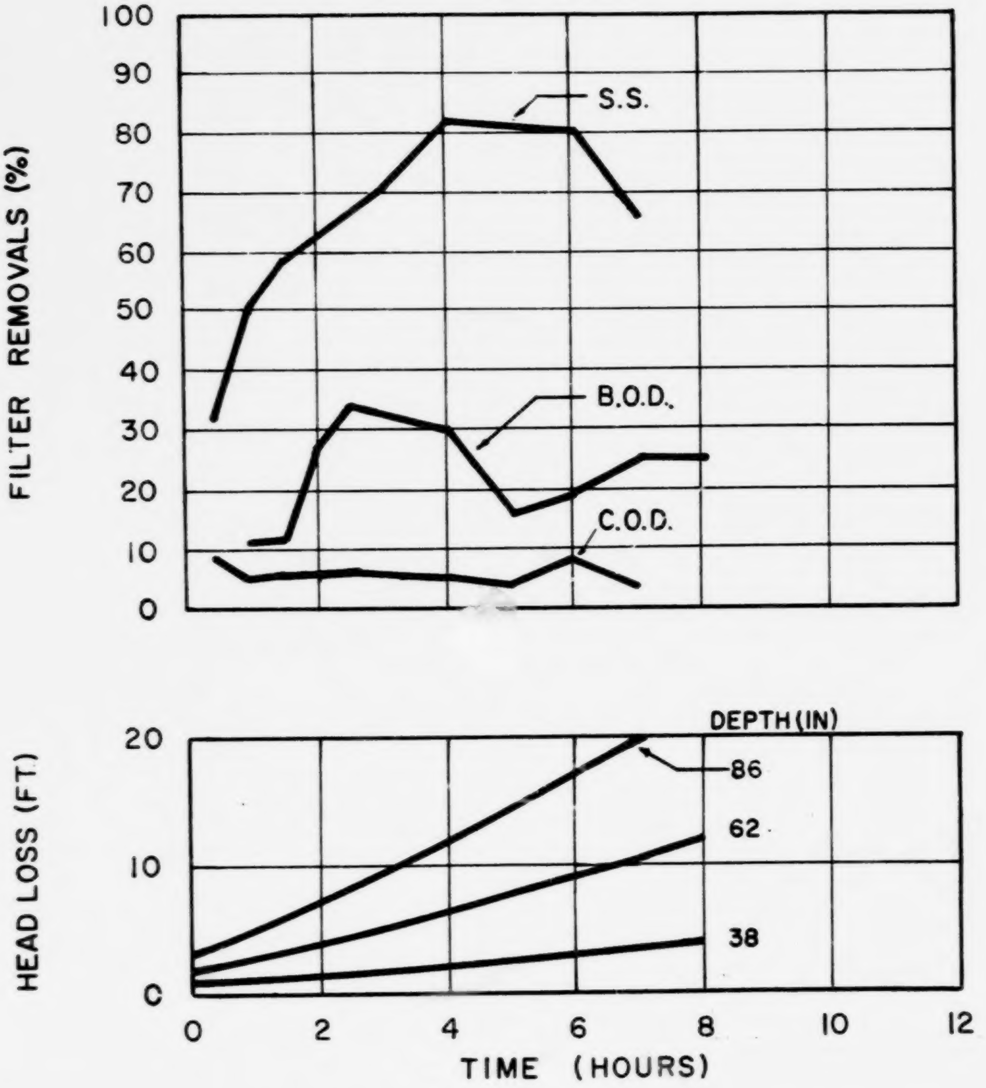
SCREEN 40 MESH. FILTER MEDIA 42 in. No. 3 ANTH./36 in. No. 612 SAND

DATE 11/15/70 FLUX RATE 32 $gpm/ft^2$ POLY. NALCO 671 0.5mg/l

RUN No. 14ASF1

**COMBINED SEWER OVERFLOW FILTRATION TEST**

**FIGURE C49**



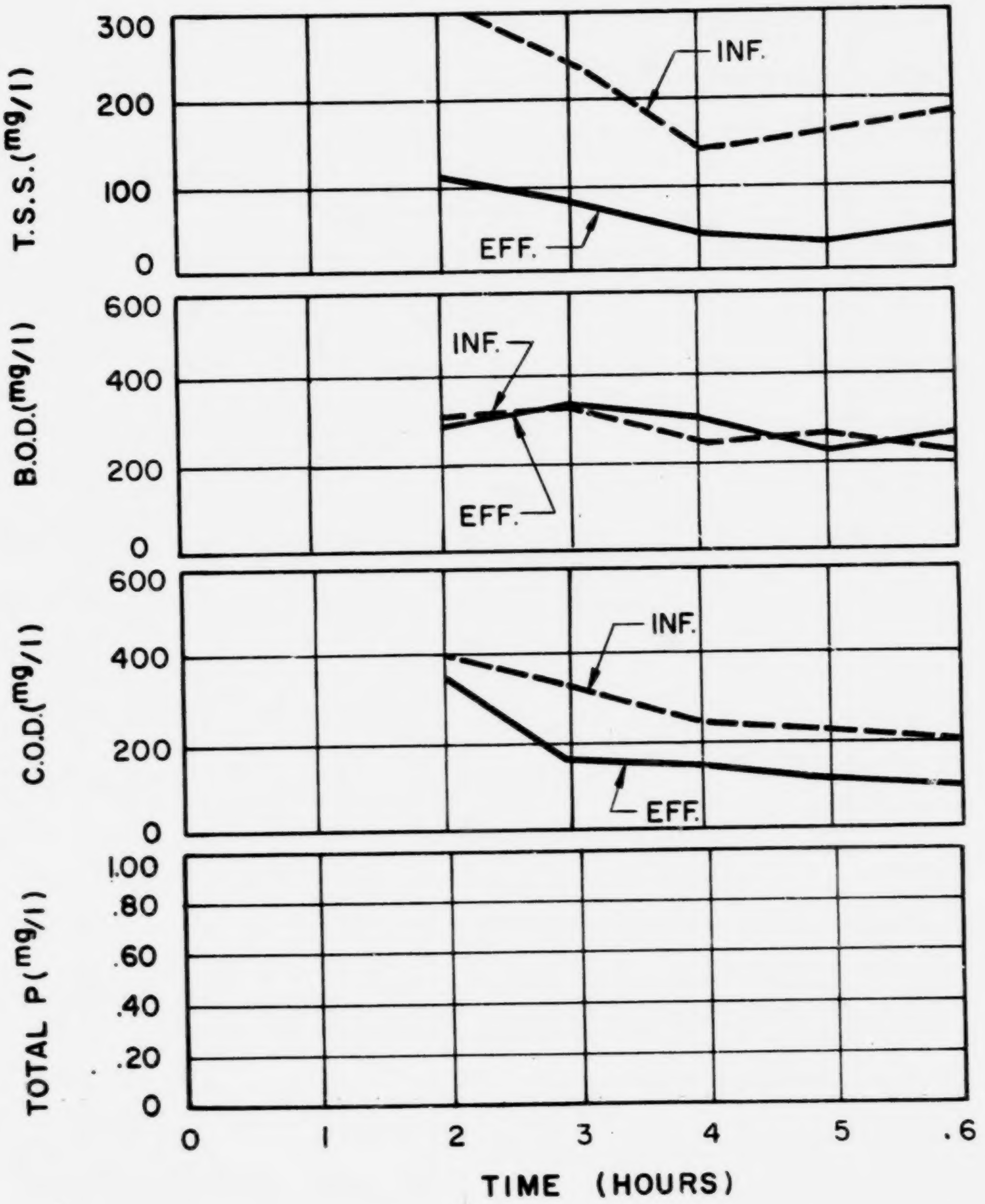
SCREEN 40 MESH. FILTER MEDIA 42 in. No. 3 ANTH./36 in. No. 612 SAND

DATE 11/15/70 FLUX RATE 32 gpm/ft$^2$ POLY. NALCO 671 0.5mg/l

RUN No. 14ASFI

## COMBINED SEWER OVERFLOW FILTRATION TEST

FIGURE C50



SCREEN 40 MESH. FILTER MEDIA 60 in. No. 3 ANTH./36 in. No. 612 SAND

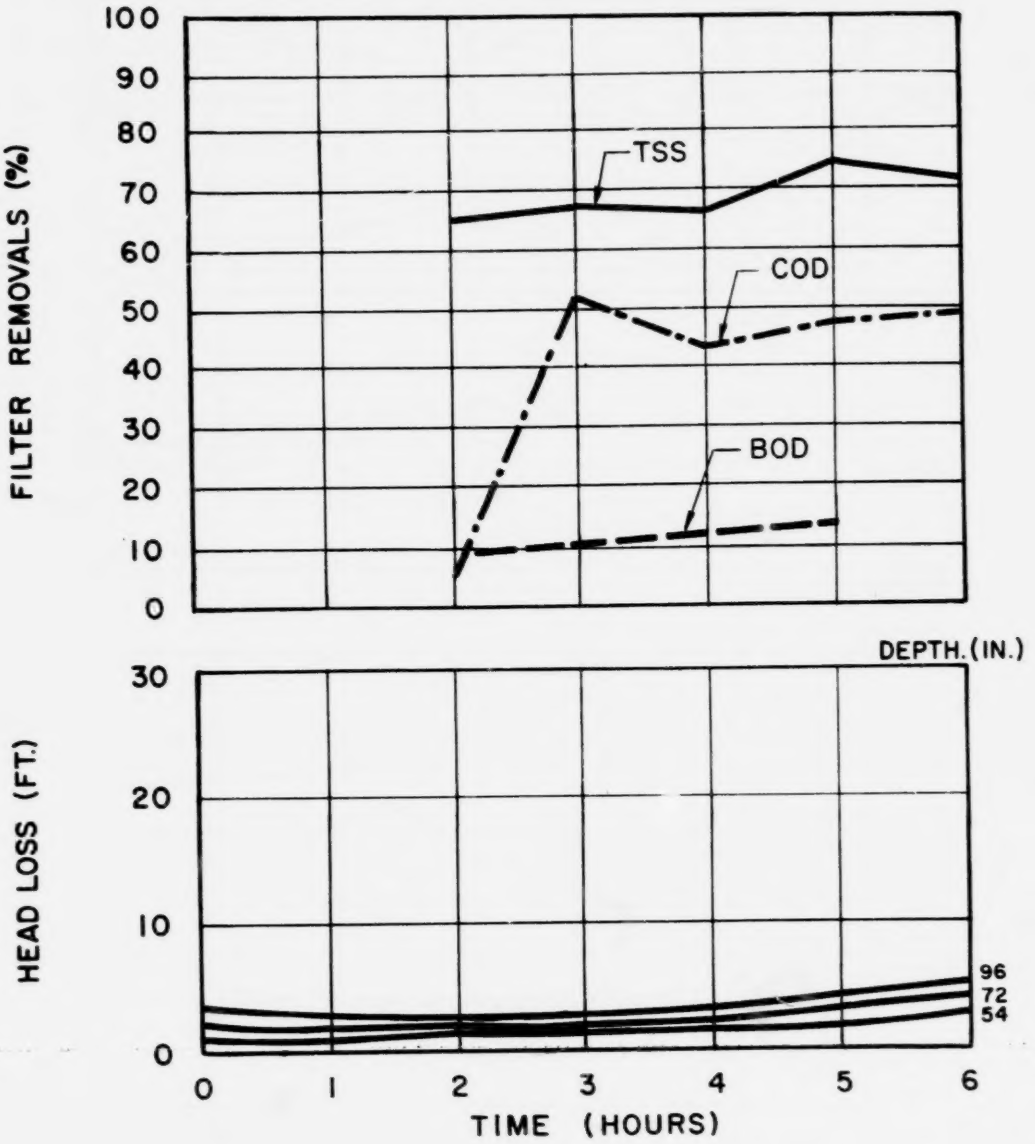
DATE 5/5/71 FLUX RATE 10 gpm/ft$^2$ COAG. 0 mg/l

POLY. 0 mg/l

Run No. 17SFII

COMBINED SEWER OVERFLOW FILTRATION TEST

FIGURE C51



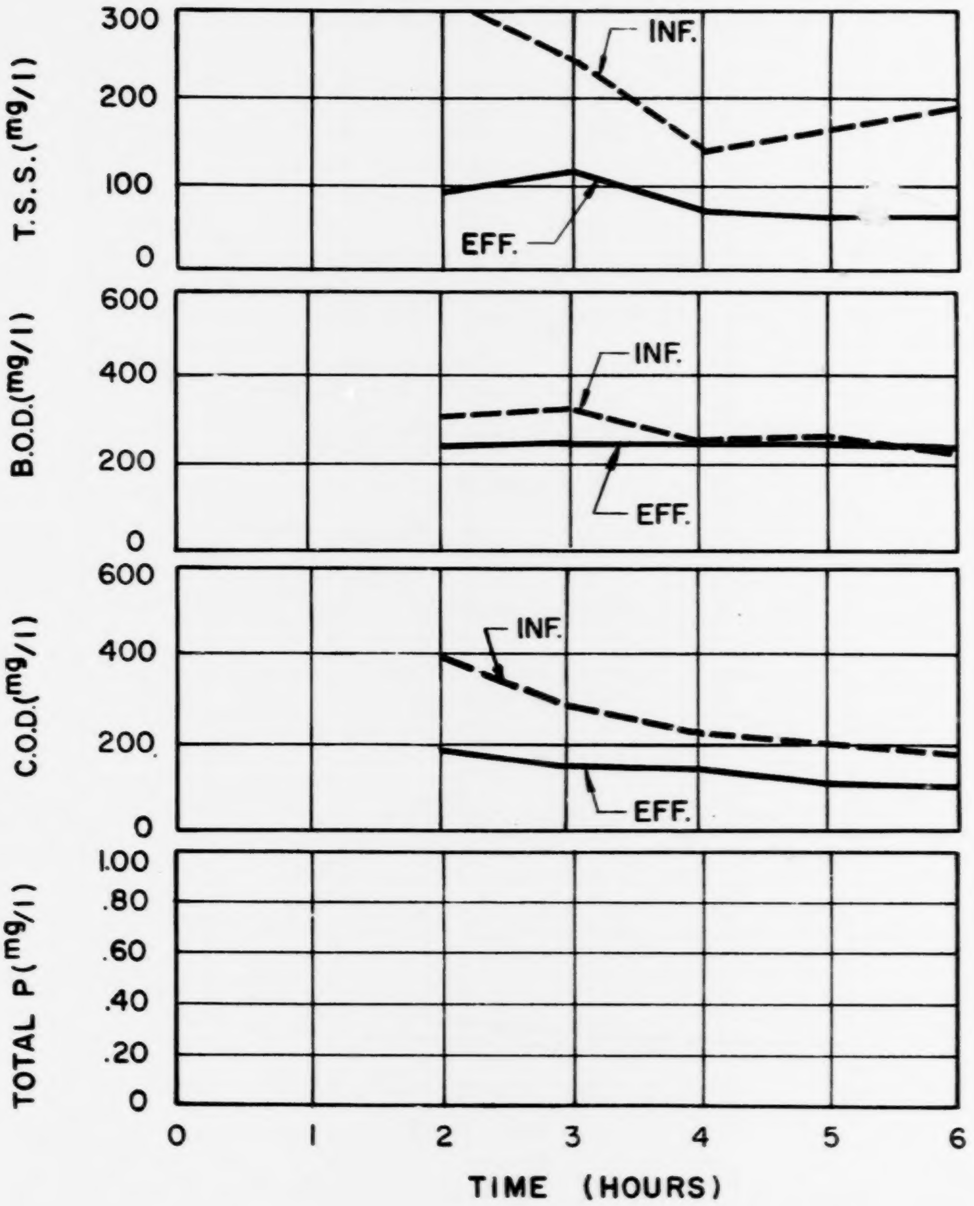
SCREEN 40 MESH. FILTER MEDIA 60 in. No. 3 ANTH./36 in. No. 612 SAND

DATE 5/5/71 FLUX RATE 10 gpm/ft$^2$ COAG. 0 mg/l
POLY. 0 mg/l

RUN No. 17SFII

COMBINED SEWER OVERFLOW FILTRATION TEST

FIGURE C52



SCREEN 40 MESH. FILTER MEDIA 60 in. No. 3 ANTH./36 in. No. 612 SAND

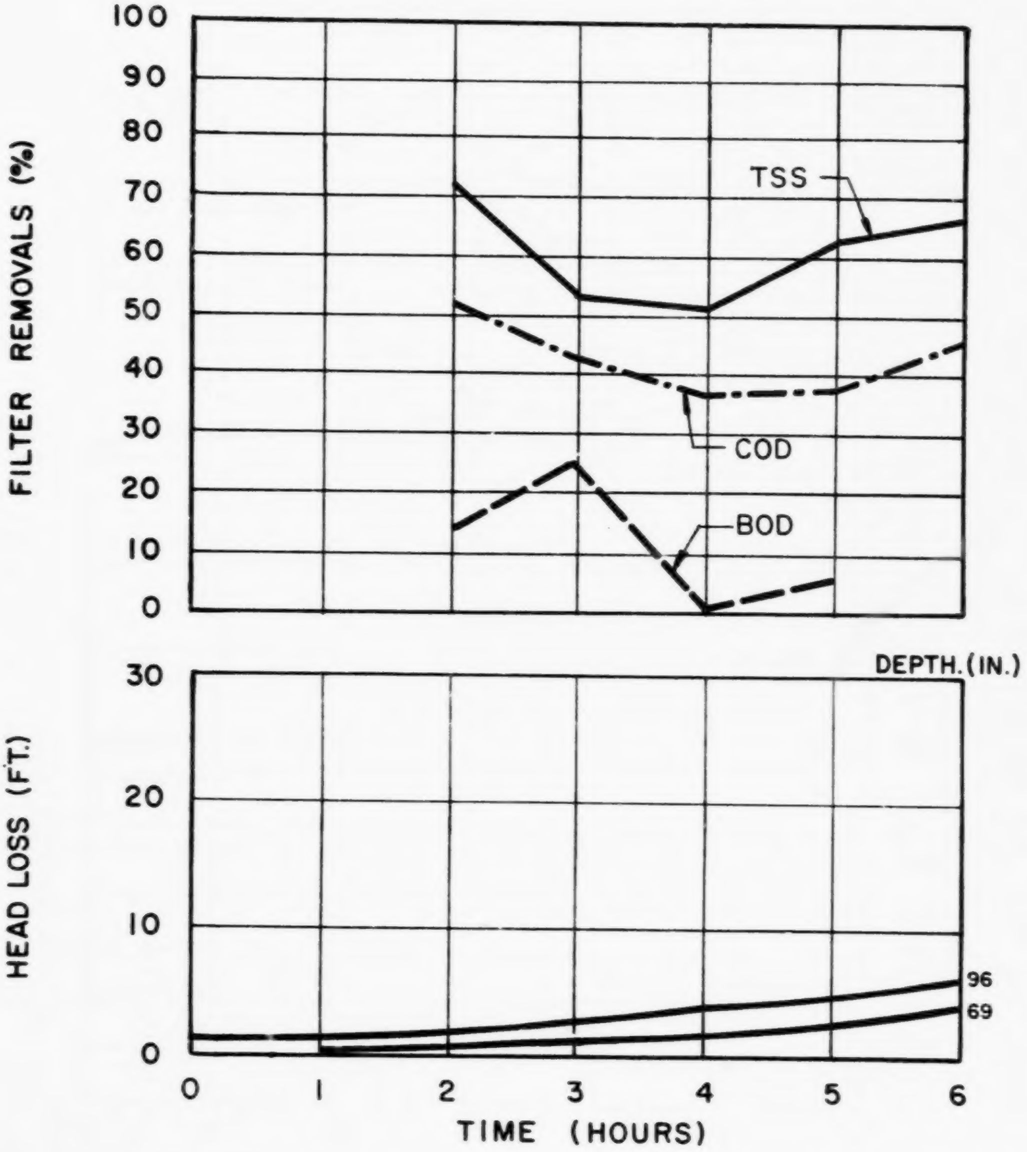
DATE 5/5/71 FLUX RATE 16 gpm/ft$^2$ COAG. 0 mg/l

POLY. 0 mg/l

RUN No. 17SFIII

COMBINED SEWER OVERFLOW FILTRATION TEST

FIGURE C53



SCREEN 40 MESH. FILTER MEDIA 60 in. No. 3 ANTH./36 in. No. 612 SAND

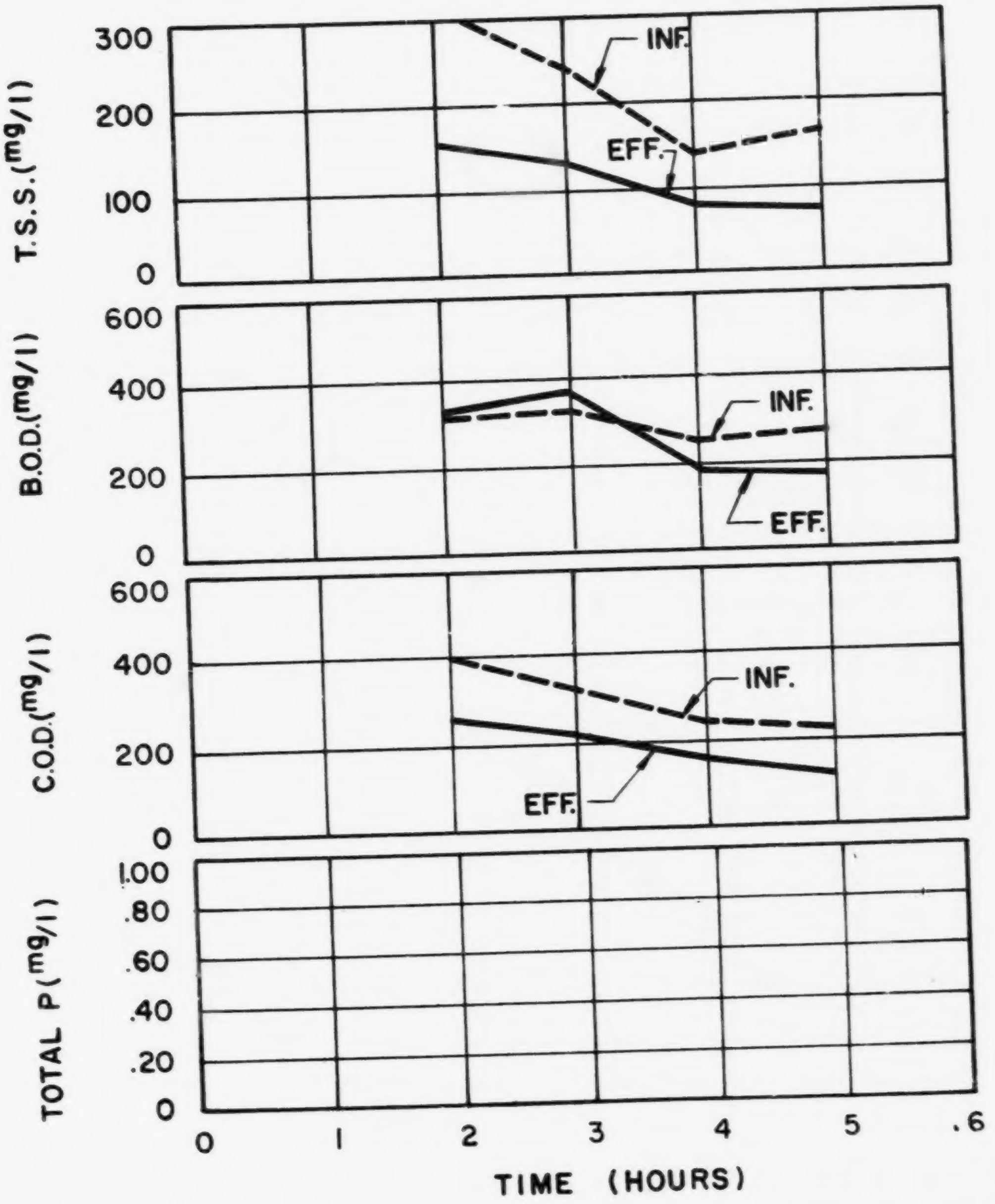
DATE 5/5/71 FLUX RATE 16 gpm/ft² COAG. 0 mg/l

POLY. 0 mg/l

RUN No. 17SFIII

COMBINED SEWER OVERFLOW FILTRATION TEST

FIGURE C54



SCREEN 40 MESH. FILTER MEDIA 60 in. No. 3 ANTH./36 in. No. 612 SAND

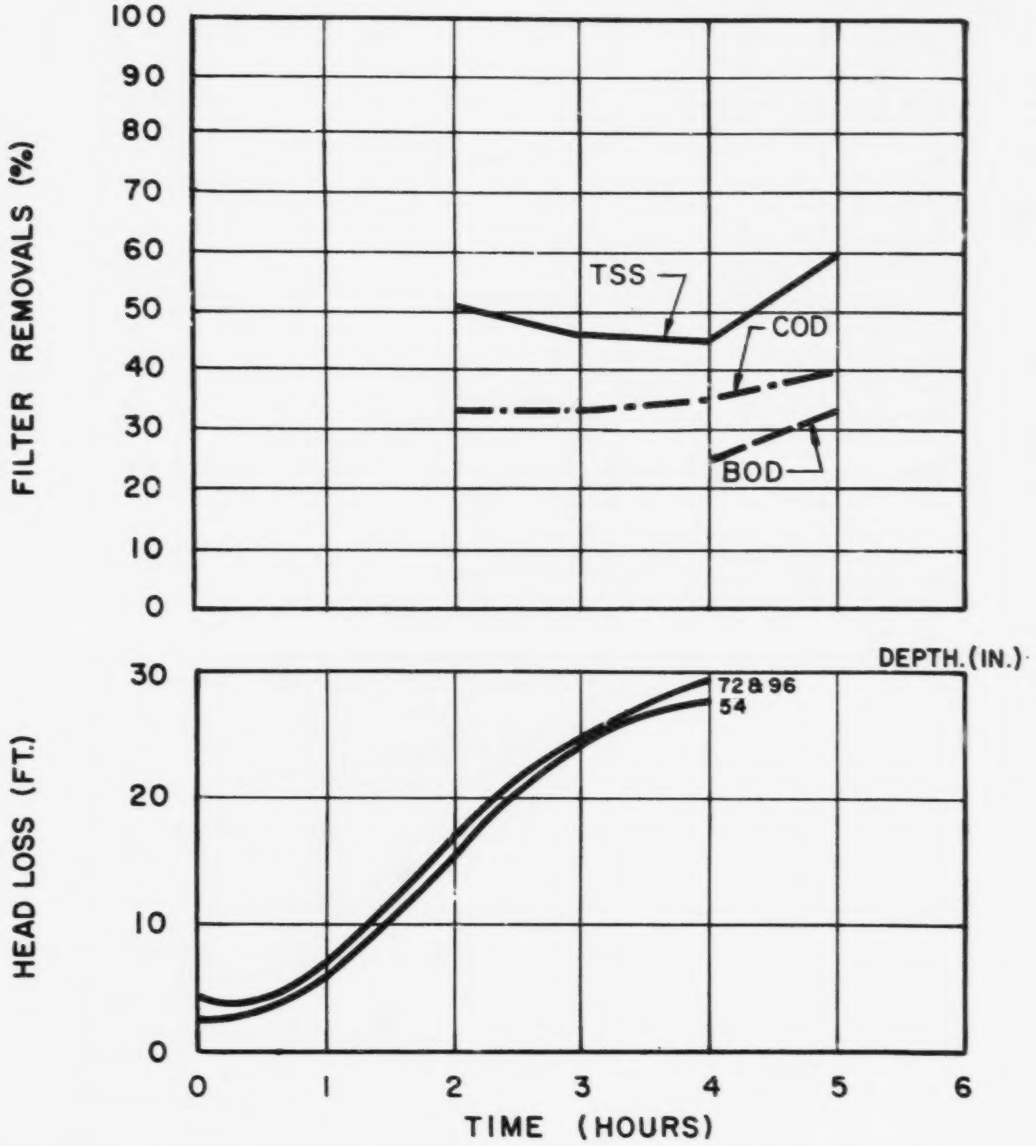
DATE 5/5/71 FLUX RATE 24 gpm/ft$^2$ COAG. 0 mg/l

POLY. 0 mg/l

RUN No. 17SFIV

## COMBINED SEWER OVERFLOW FILTRATION TEST

FIGURE C55



SCREEN 40 MESH. FILTER MEDIA 60 in. No. 3 ANTH./36 in. No. 612 SAND

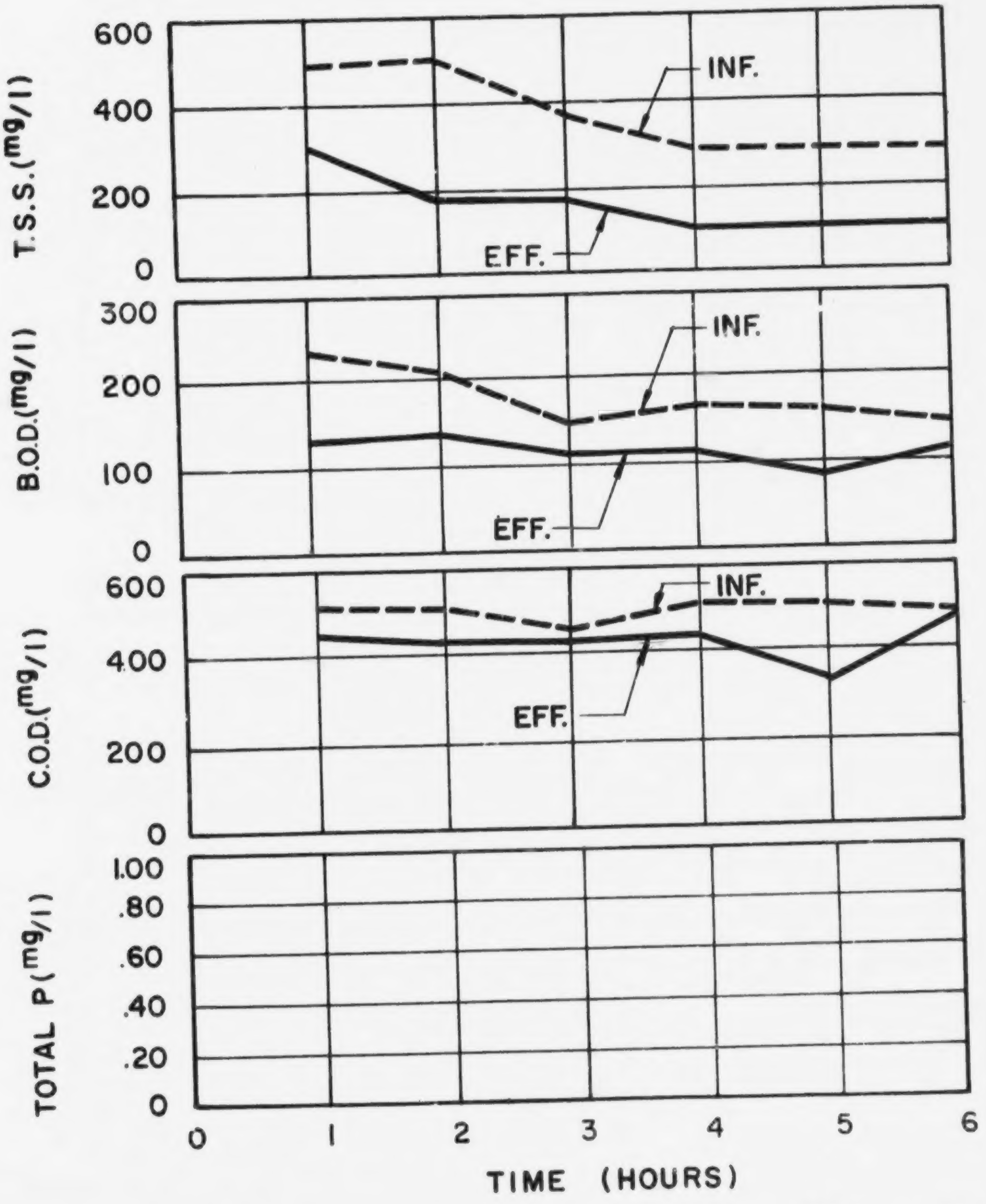
DATE 5/5/71 FLUX RATE 24 gpm/ft² COAG. 0 mg/l

POLY. 0 mg/l

RUN No. 17SFIV

**COMBINED SEWER OVERFLOW FILTRATION TEST**

FIGURE C56



SCREEN 40 MESH. FILTER MEDIA 60 in. No. 3 ANTH./36 in. No. 612 SAND

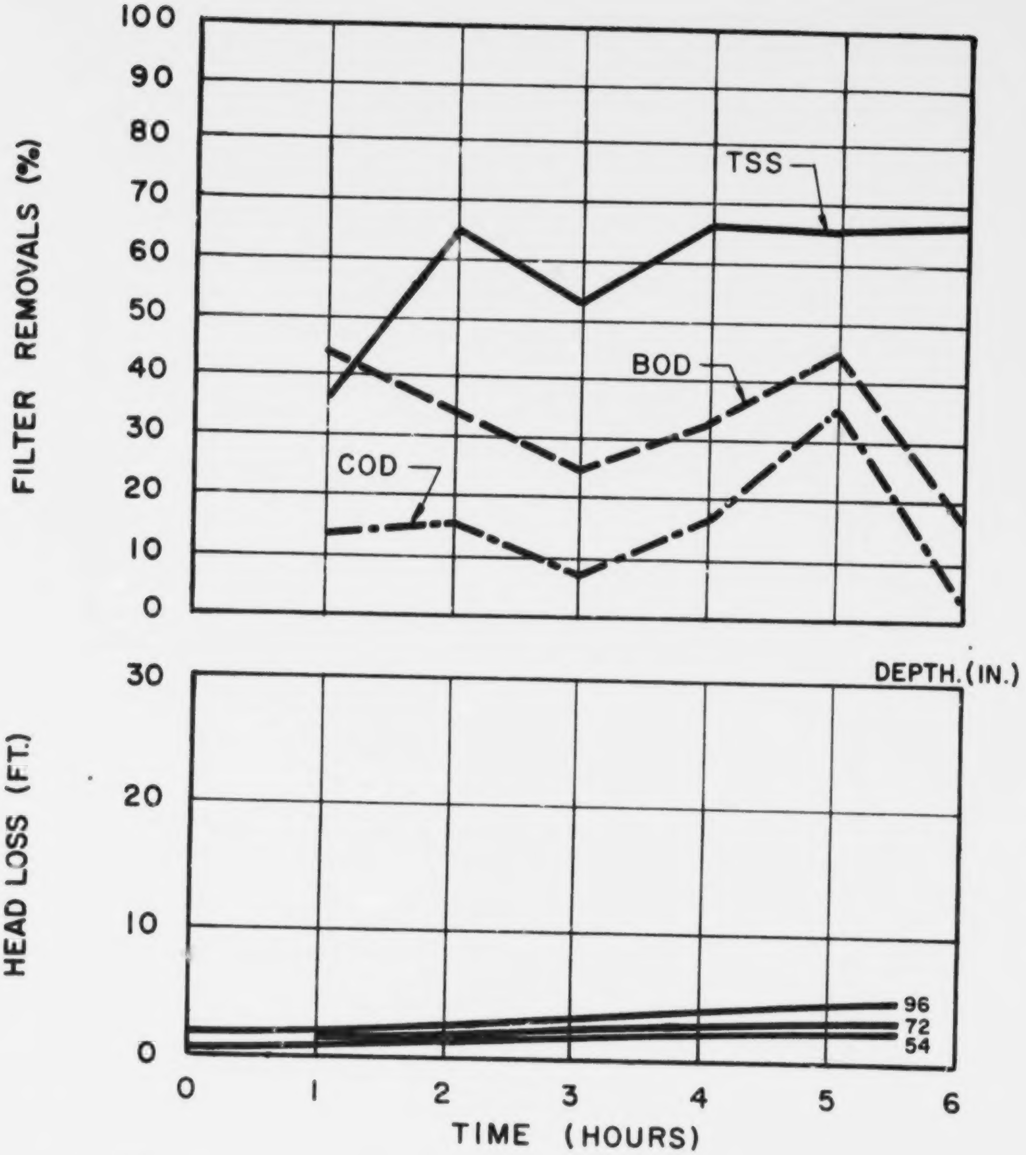
DATE 6/7/71 FLUX RATE 8 gpm/ft$^2$ COAG. 0 mg/l

POLY. ATLA. 4A4 1.0 mg/l

RUN No. 18SFII

COMBINED SEWER OVERFLOW FILTRATION TEST

FIGURE C 57



SCREEN 40 MESH. FILTER MEDIA 60 in. No. 3 ANTH./36 in. No. 612 SAND

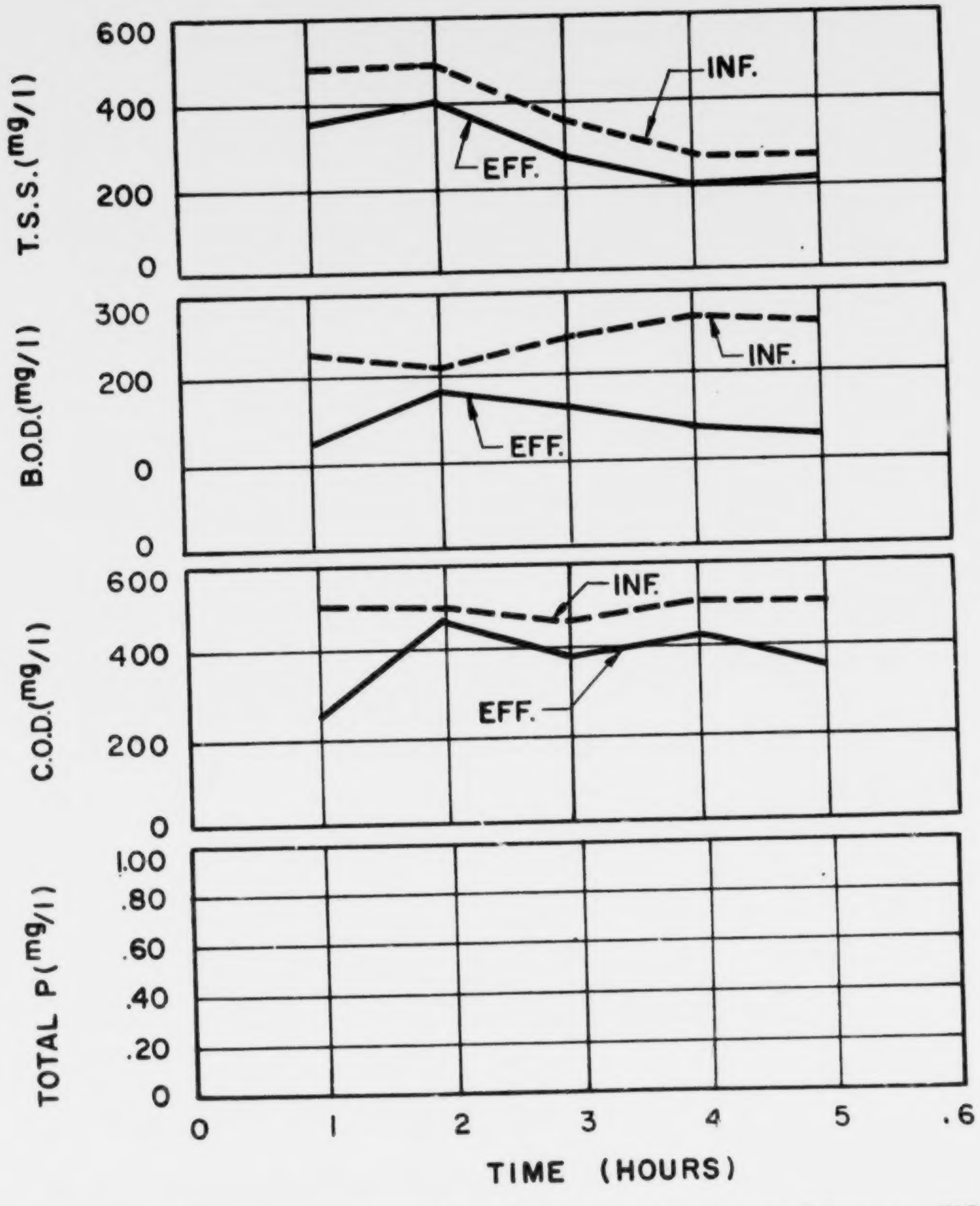
DATE 6/7/71 FLUX RATE 8 gpm/ft² COAG. 0 mg/l

POLY. ATLA. 4A4 1.0 mg/l

RUN No. 18SFII

## COMBINED SEWER OVERFLOW FILTRATION TEST

FIGURE C58



SCREEN 40 MESH. FILTER MEDIA 60 in. No. 3 ANTH./36 in. No. 612 SAND

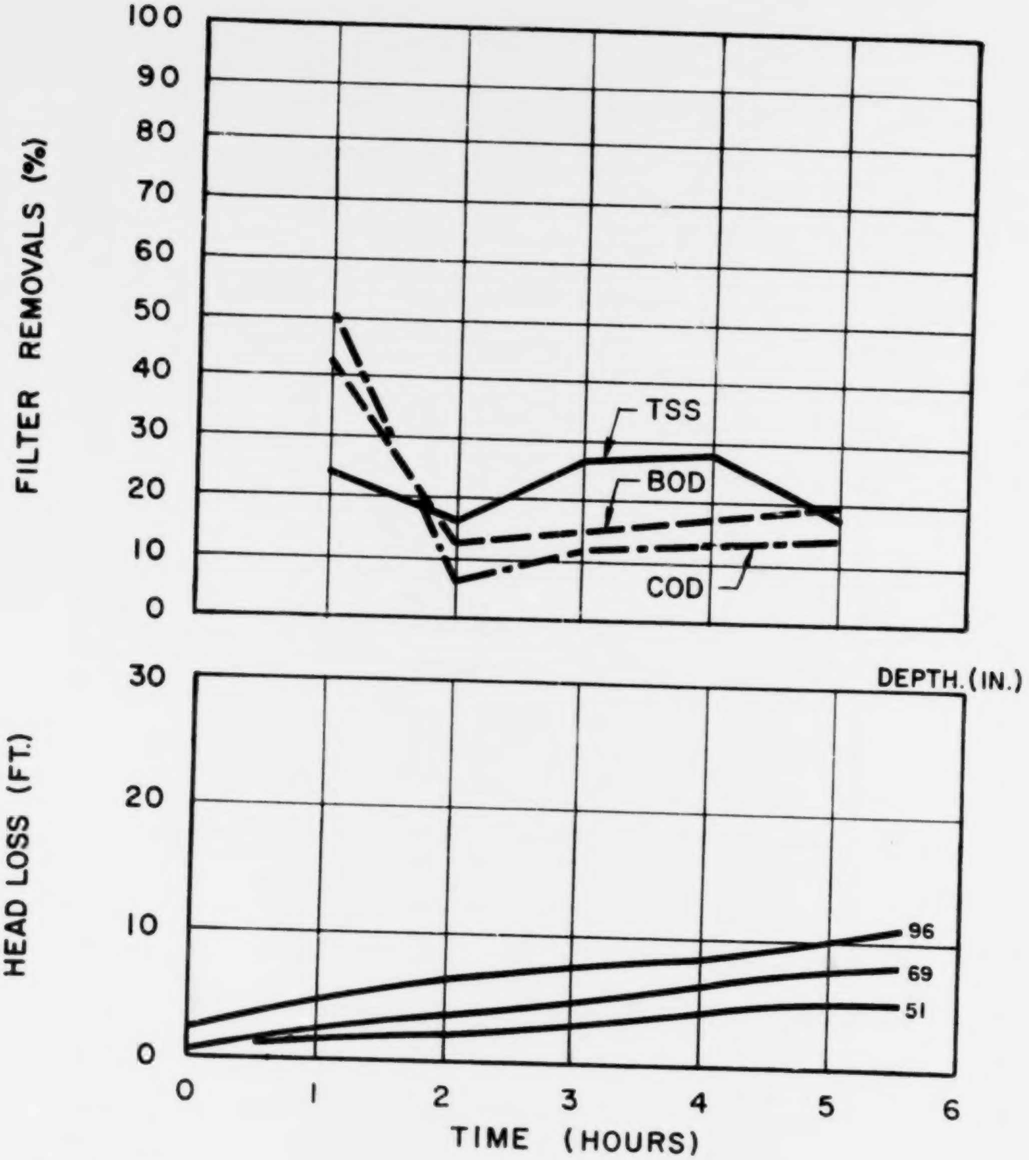
DATE 6/7/71 FLUX RATE 24 gpm/ft$^2$ COAG. 0 mg/l

POLY. ATL A. 4A4 1.0 mg/l

RUN No. 18 SF III

## COMBINED SEWER OVERFLOW FILTRATION TEST

FIGURE C 59



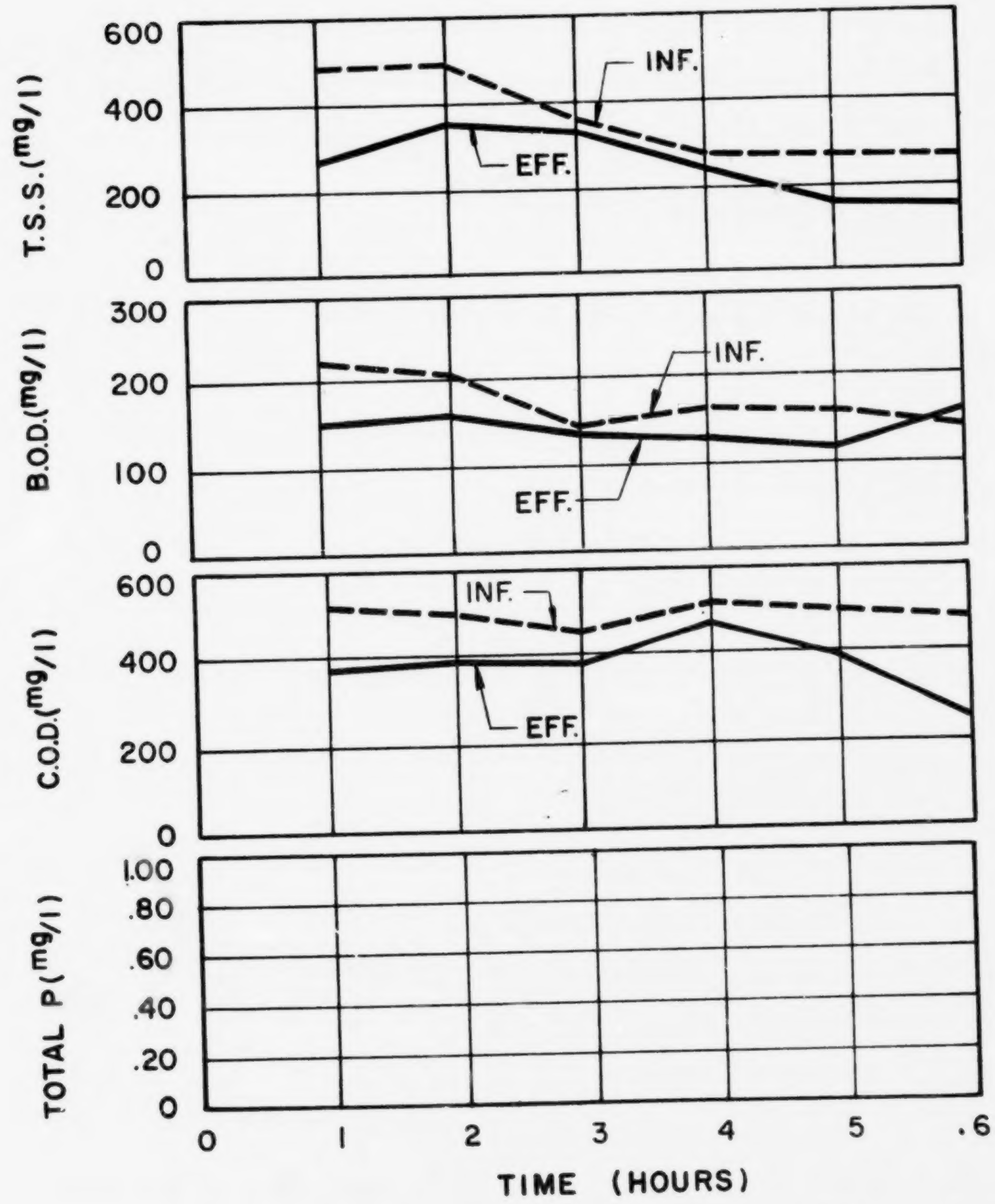
SCREEN 40 MESH. FILTER MEDIA 60 in. No. 3 ANTH./36 in. No. 612 SAND

DATE 6/7/71 FLUX RATE 24 gpm/ft$^2$ COAG. 0 mg/l

RUN No. 18SFIII POLY. ATLA. 4A4 1.0 mg/l

**COMBINED SEWER OVERFLOW FILTRATION TEST**

FIGURE C60



SCREEN 40 MESH. FILTER MEDIA 60 in. No. 3 ANTH./36 in. No. 612 SAND

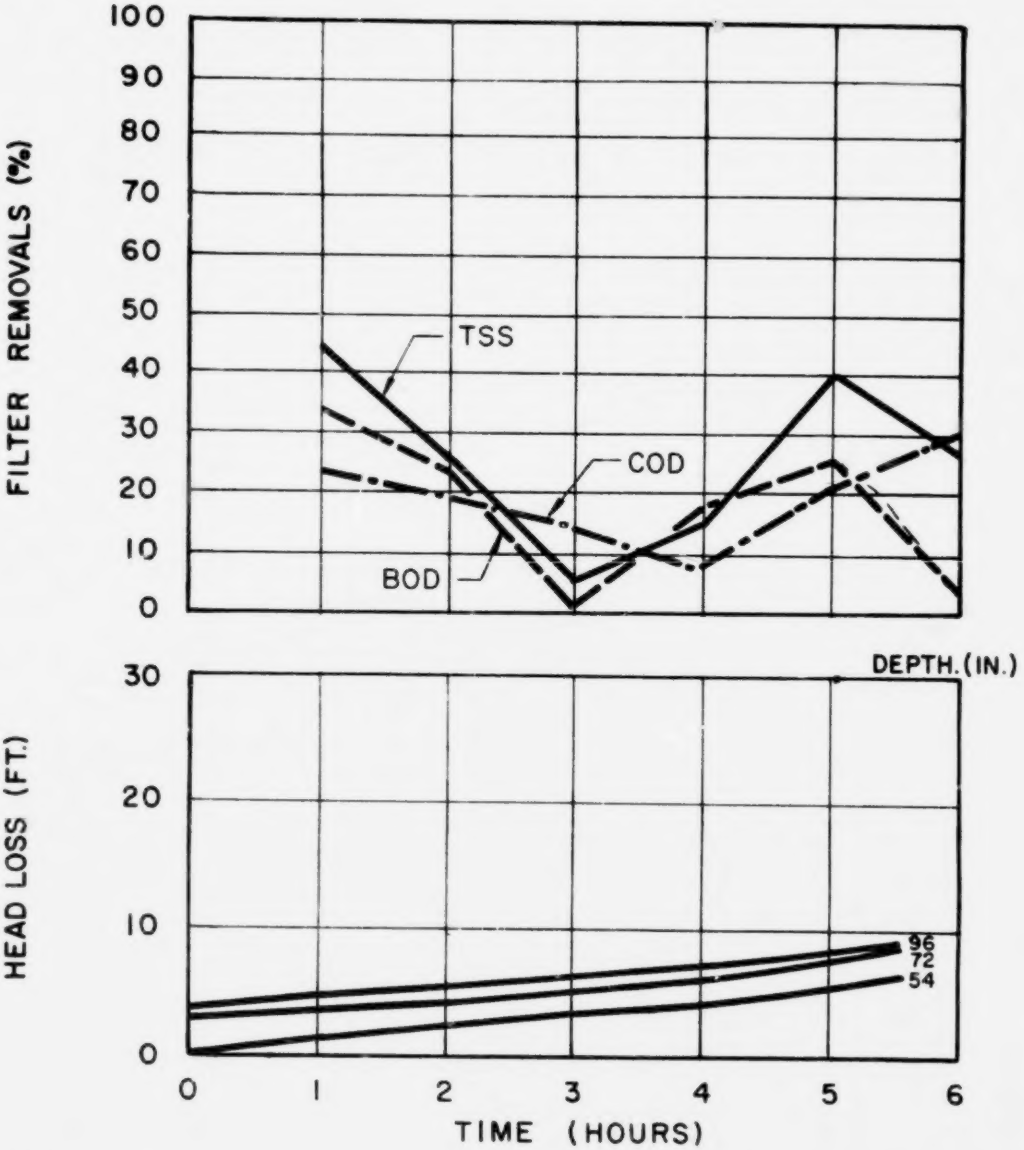
DATE 6/7/71 FLUX RATE 16 gpm/ft$^2$ COAG. 0 mg/l

POLY. ATLA. 4A4 1.0 mg/l

RUN No. 18SFIV

COMBINED SEWER OVERFLOW FILTRATION TEST

FIGURE C61



SCREEN 40 MESH. FILTER MEDIA 60 in. No. 3 ANTH./36 in. No. 612 SAND

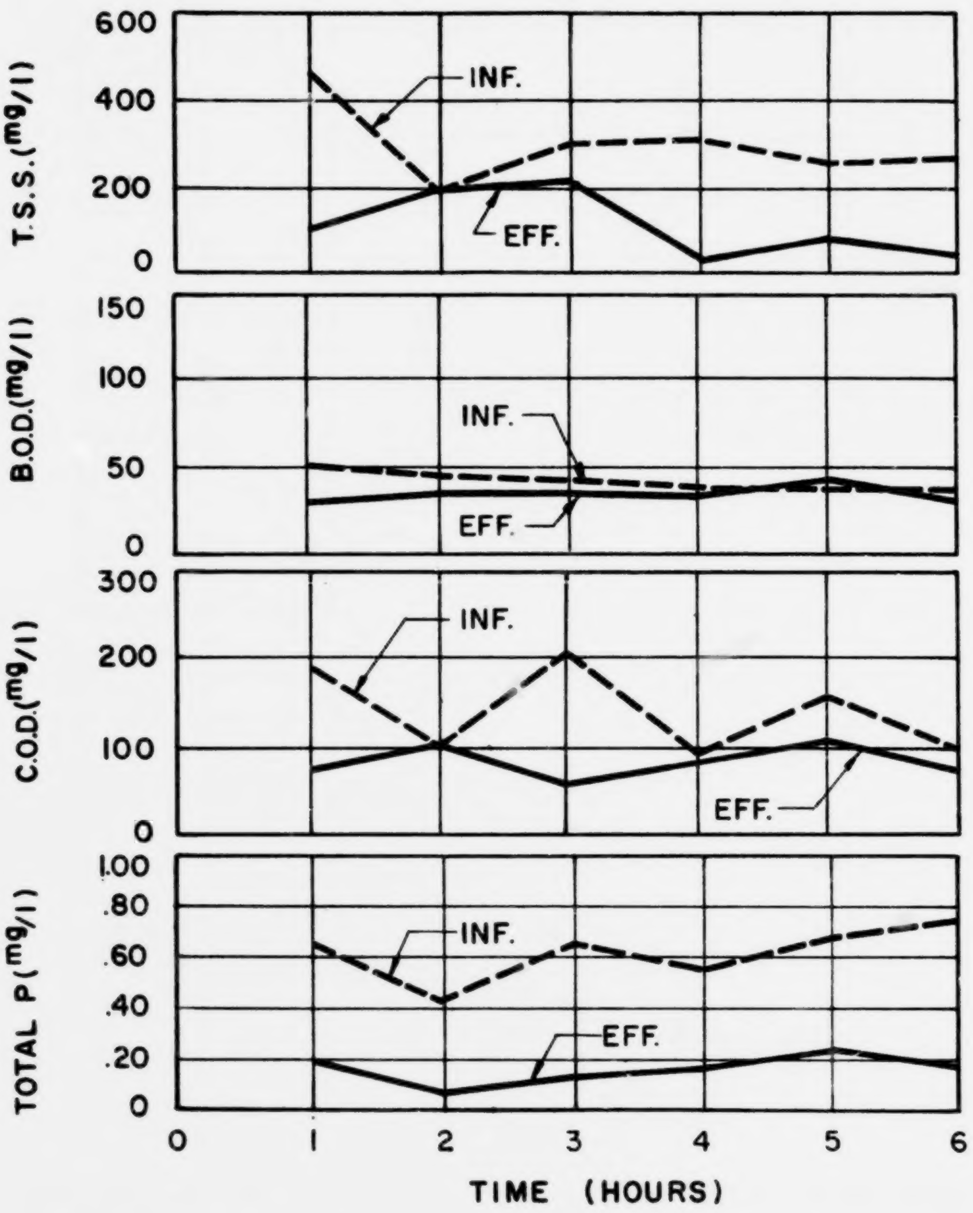
DATE 6/7/71 FLUX RATE 16 gpm/ft² COAG. 0 mg/l

POLY. ATLA. 4A4 1.0 mg/l

RUN No. 18SF1V

COMBINED SEWER OVERFLOW FILTRATION TEST

FIGURE C62



SCREEN 40 MESH. FILTER MEDIA 60 in. No. 3 ANTH. / 36 in. No. 612 SAND

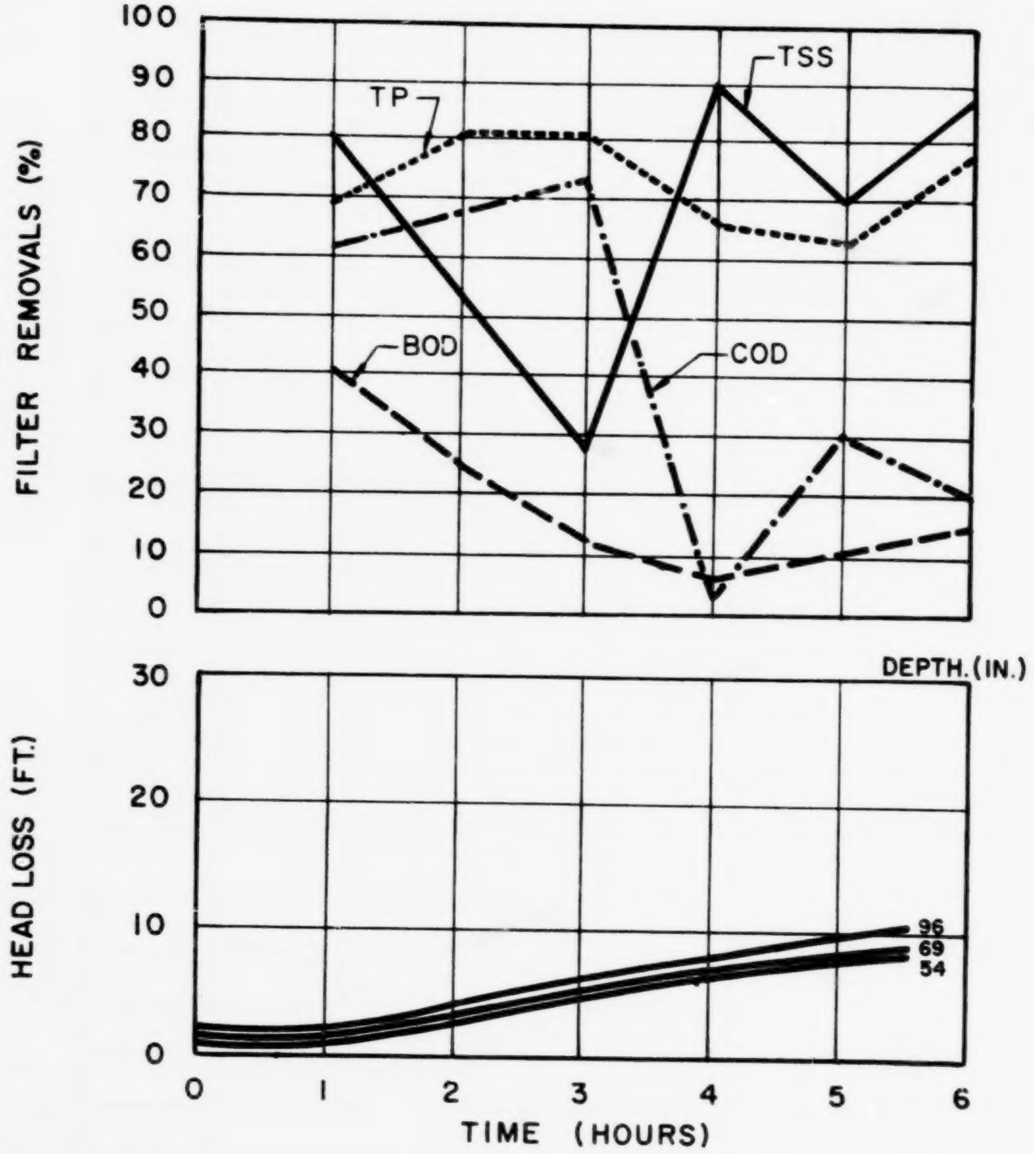
DATE 6/20/71 FLUX RATE 8 gpm/ft$^2$ COAG. ALUM. 30.0 mg/l

POLY. MAG. 560C 1.0 mg/l

RUN No. 19SFIII

COMBINED SEWER OVERFLOW FILTRATION TEST

FIGURE C63



SCREEN 40 MESH. FILTER MEDIA 60 in. No. 3 ANTH./ 36 in. No. 612 SAND

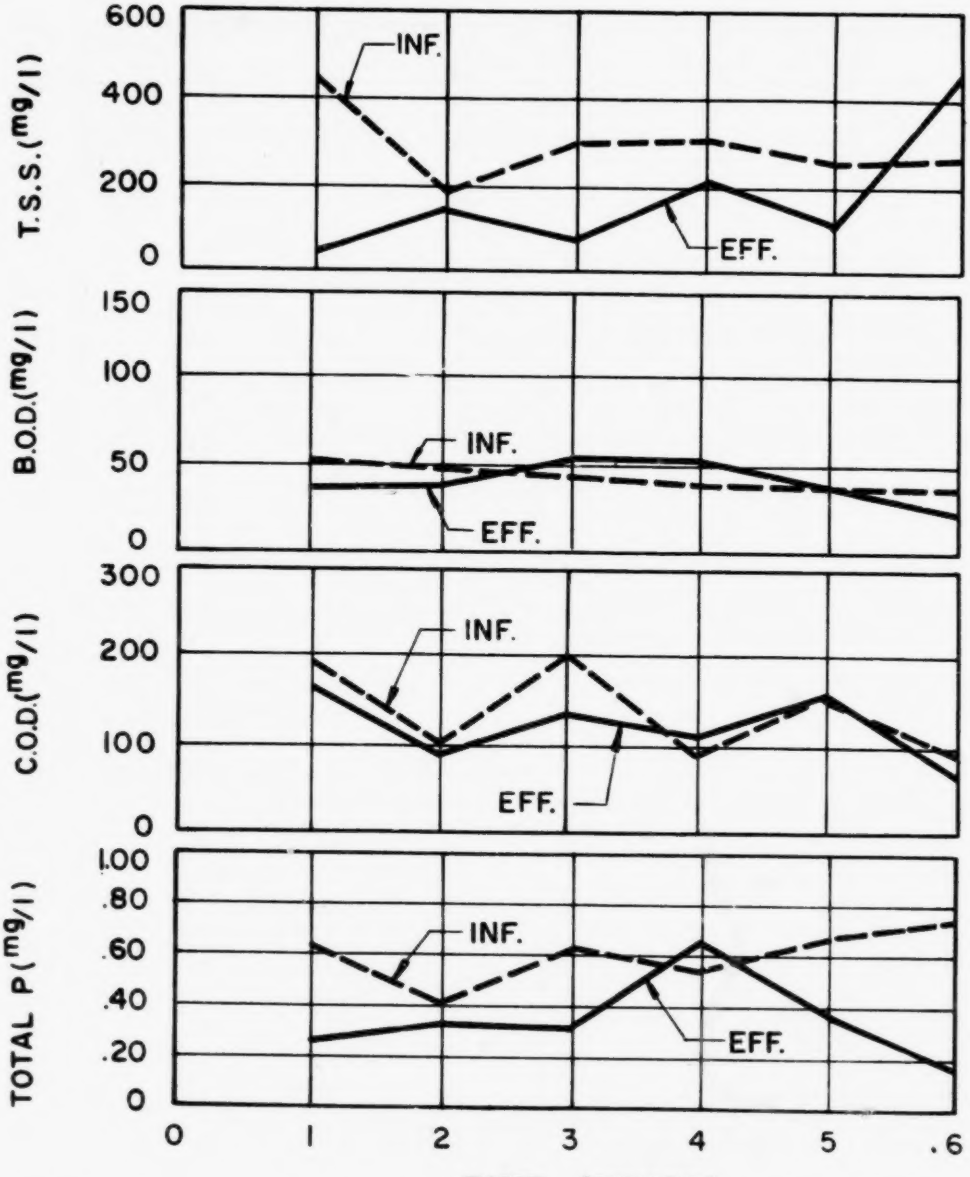
DATE 6/20/71 FLUX RATE 8 gpm/ft² COAG. ALUM 30.0 mg/l

POLY. MAG.560C 1.0 mg/l

RUN No. 19SFIII

COMBINED SEWER OVERFLOW FILTRATION TEST

FIGURE C64



SCREEN 40 MESH. FILTER MEDIA 60 in. No. 3 ANTH./36 in. No. 612 SAND

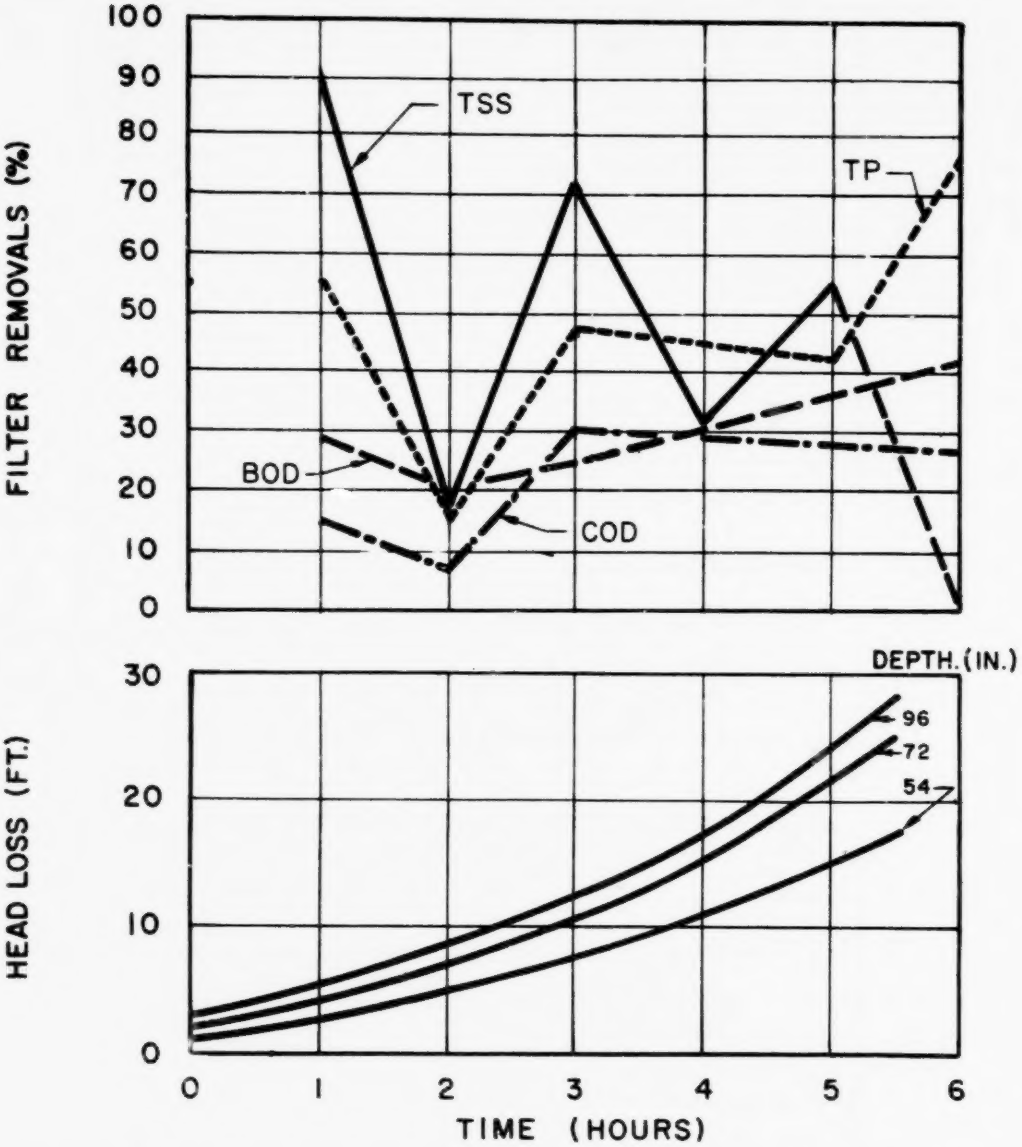
DATE 6/20/71 FLUX RATE 16 gpm/ft$^2$ COAG ALUM. 30 mg/l

POLY. MAG. 560C 1.0 mg/l

RUN No. 19SF V

**COMBINED SEWER OVERFLOW FILTRATION TEST**

FIGURE C 65



SCREEN 40 MESH. FILTER MEDIA 60 in. No. 3 ANTH./36 in. No. 612 SAND

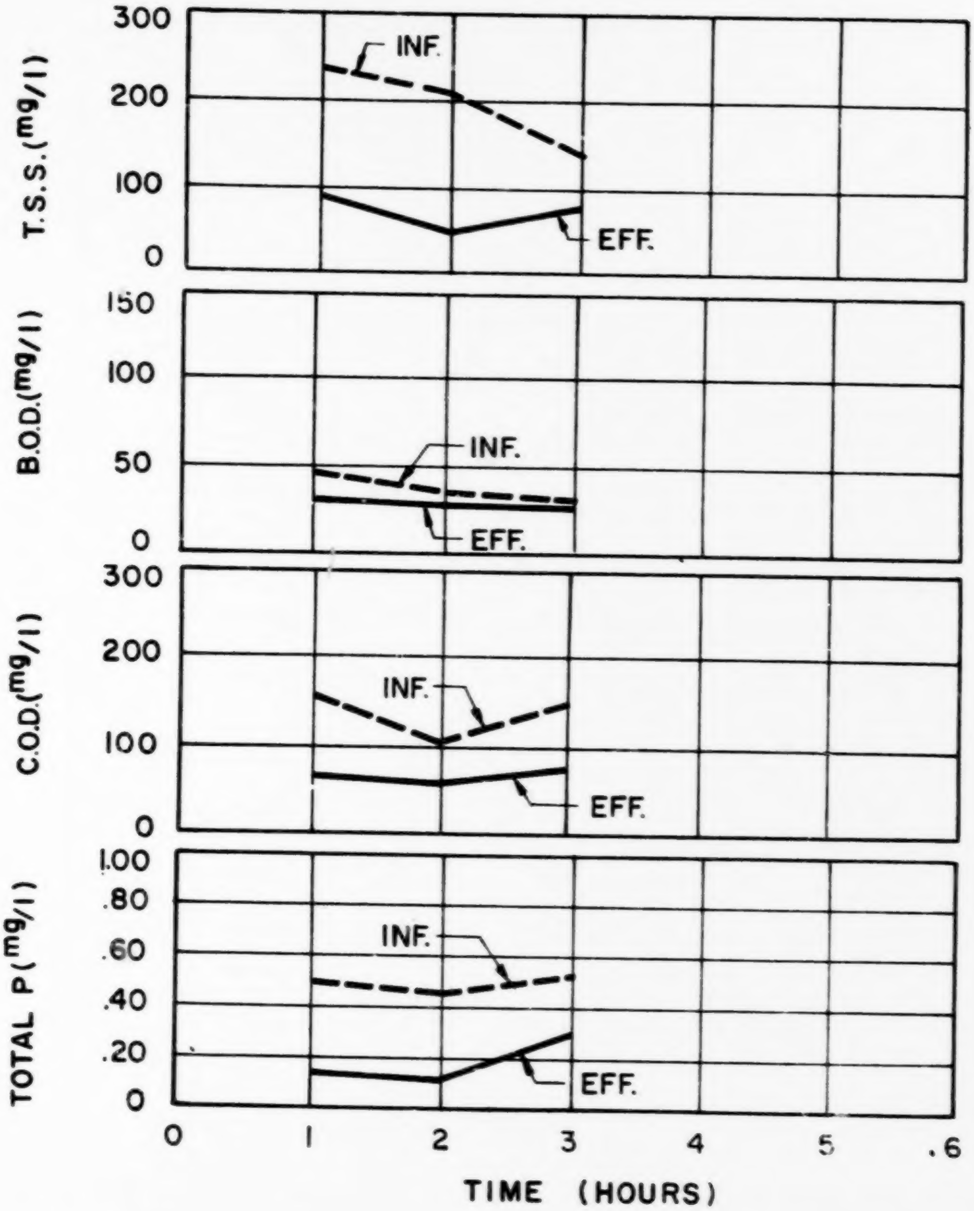
DATE 6/20/71 FLUX RATE 16 gpm/ft$^2$ COAG. ALUM 30 mg/l

POLY. MAG. 560C 1.0 mg/l

RUN No. 19SF1V

**COMBINED SEWER OVERFLOW FILTRATION TEST**

FIGURE C 66



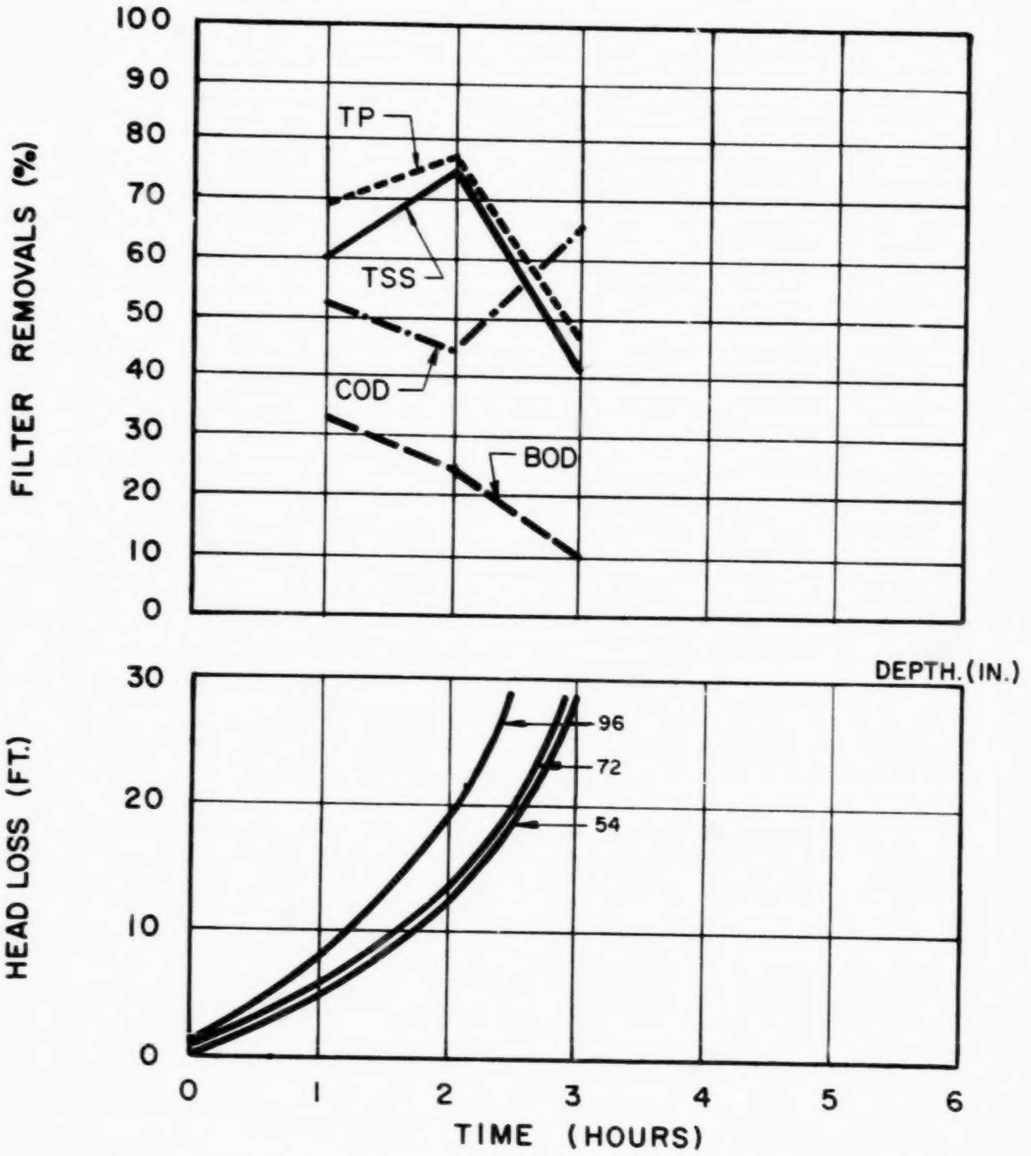
SCREEN 40 MESH. FILTER MEDIA 60 in. No. 3 ANTH./36 in. No. 612 SAND

DATE 6/21/71 FLUX RATE 24 gpm/ft$^2$ COAG. ALUM. 30 mg/l

RUN No. 19ASFII POLY. MAG. 560C 1.0 mg/l

## COMBINED SEWER OVERFLOW FILTRATION TEST

FIGURE C 67



SCREEN 40 MESH. FILTER MEDIA 60 in. No. 3 ANTH./36 in. No. 612 SAND

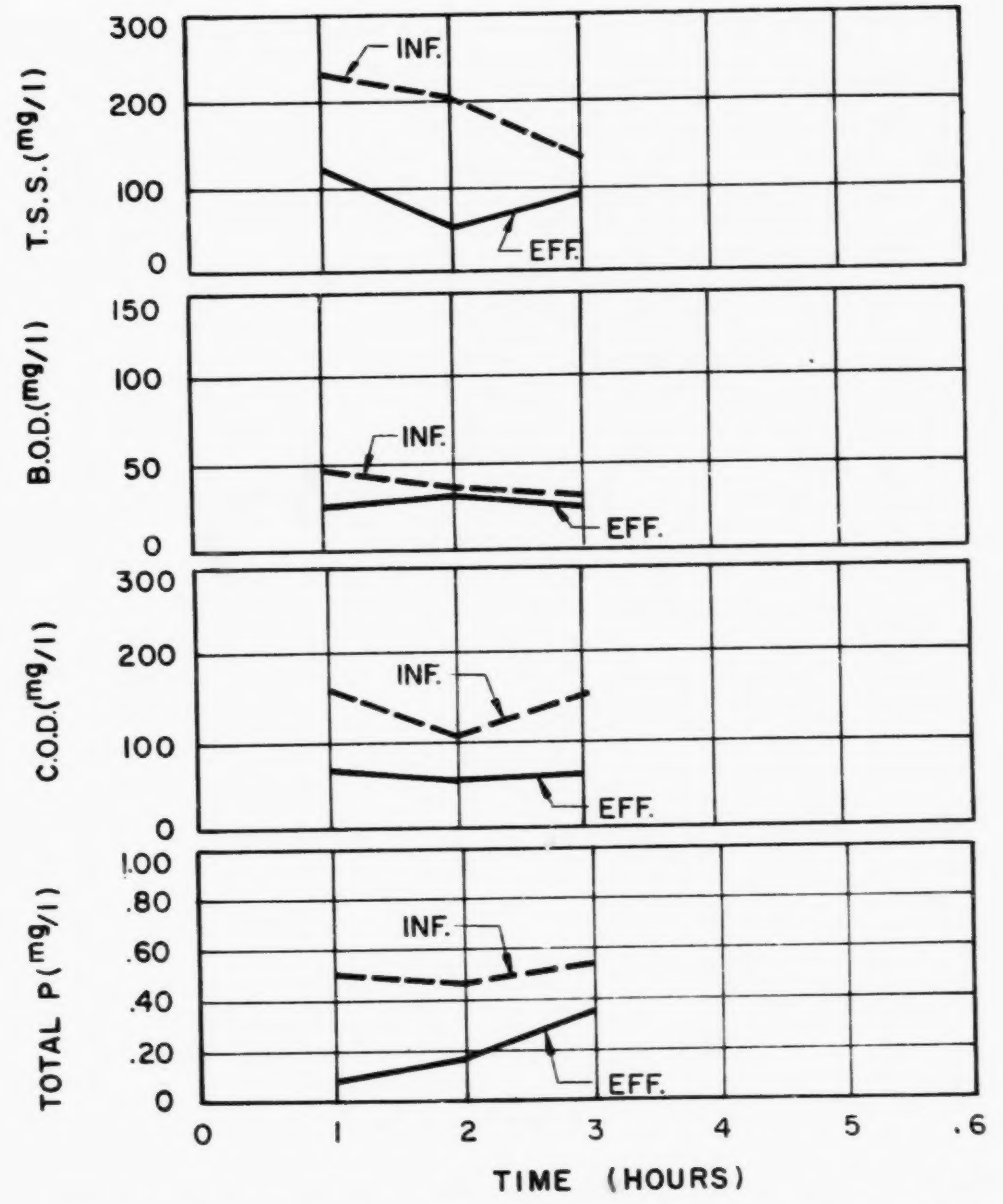
DATE 6/21/71 FLUX RATE 24 gpm/ft² COAG. ALUM 30 mg/l

POLY. MAG. 560C 1.0 mg/l

RUN No. 19ASFII

COMBINED SEWER OVERFLOW FILTRATION TEST

FIGURE C68



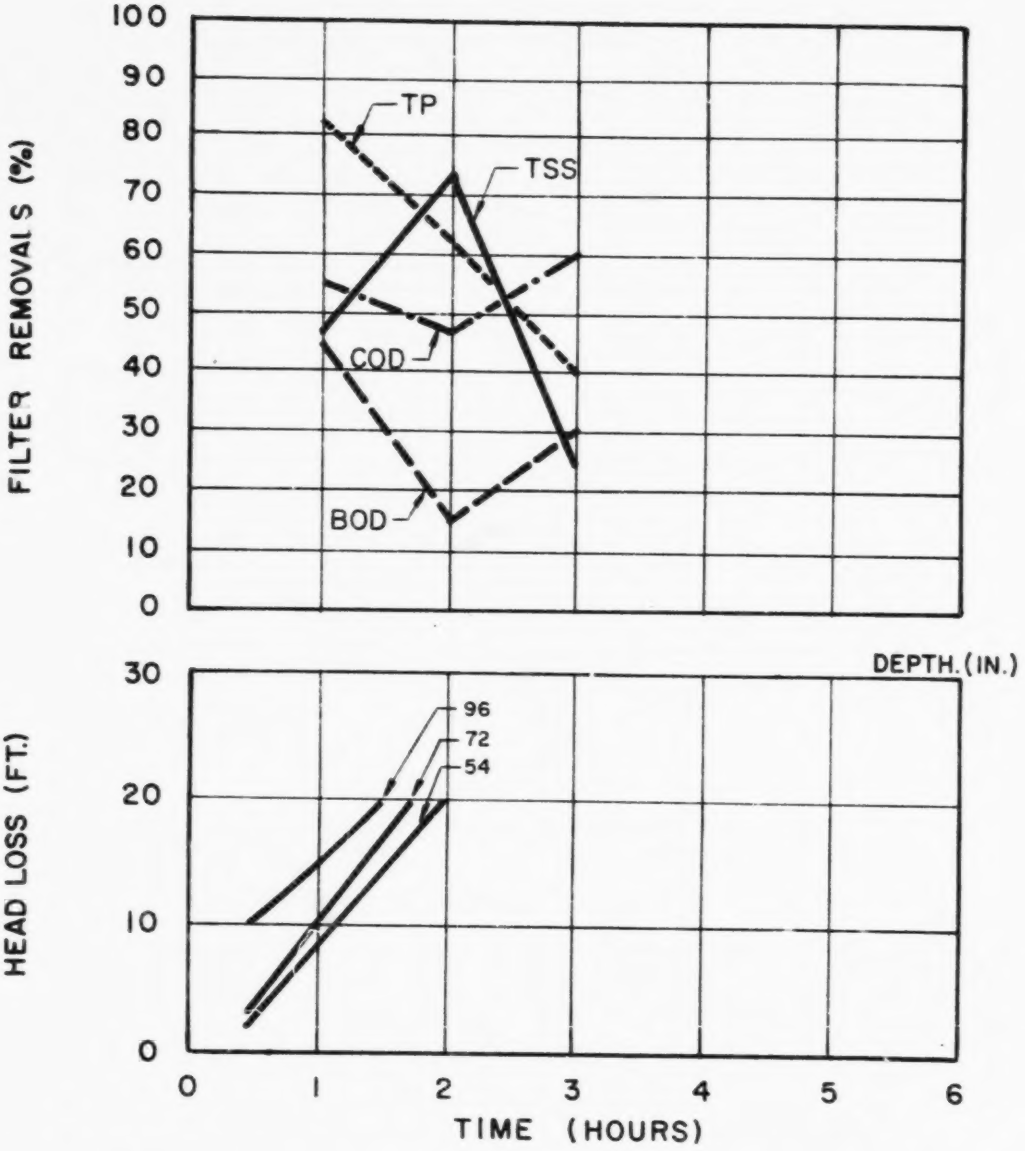
SCREEN 40 MESH. FILTER MEDIA 60 in. No. 3 ANTH./36 in. No. 612 SAND

DATE 6/21/71 FLUX RATE 32 gpm/ft$^2$ COAG. ALUM. 30 mg/l

RUN No. 19 ASFIV POLY. MAG. 560C 1.0 mg/l

**COMBINED SEWER OVERFLOW FILTRATION TEST**

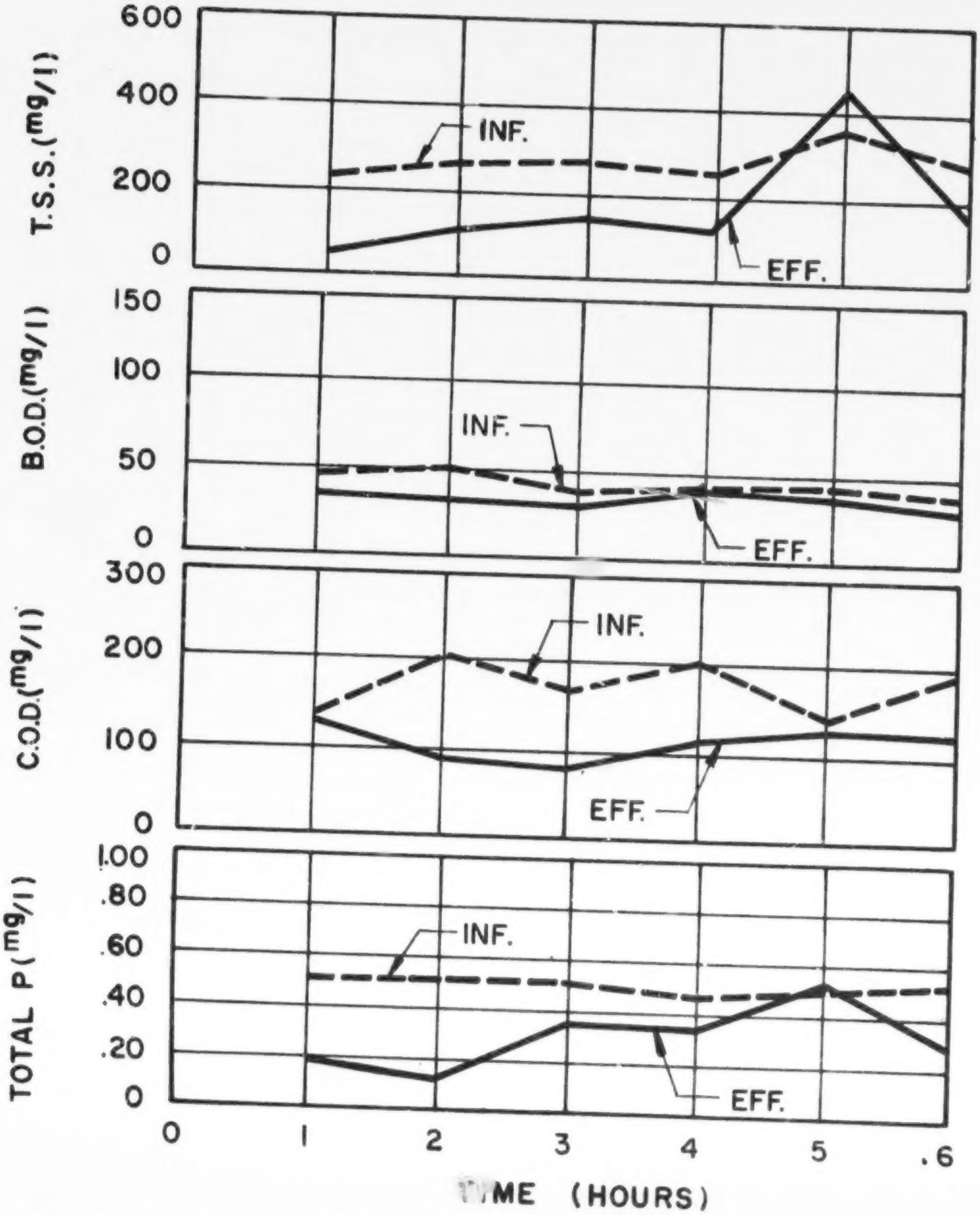
FIGURE C69



SCREEN 40 MESH. FILTER MEDIA 60 in. No. 3 ANTH./36 in. No. 612 SAND
DATE 6/21/71 FLUX RATE 32 gpm/ft$^2$ COAG. ALUM 30 mg/l
POLY. MAG. 560C 1.0 mg/l
RUN No. 19ASFIV

**COMBINED SEWER OVERFLOW FILTRATION TEST**

FIGURE C70



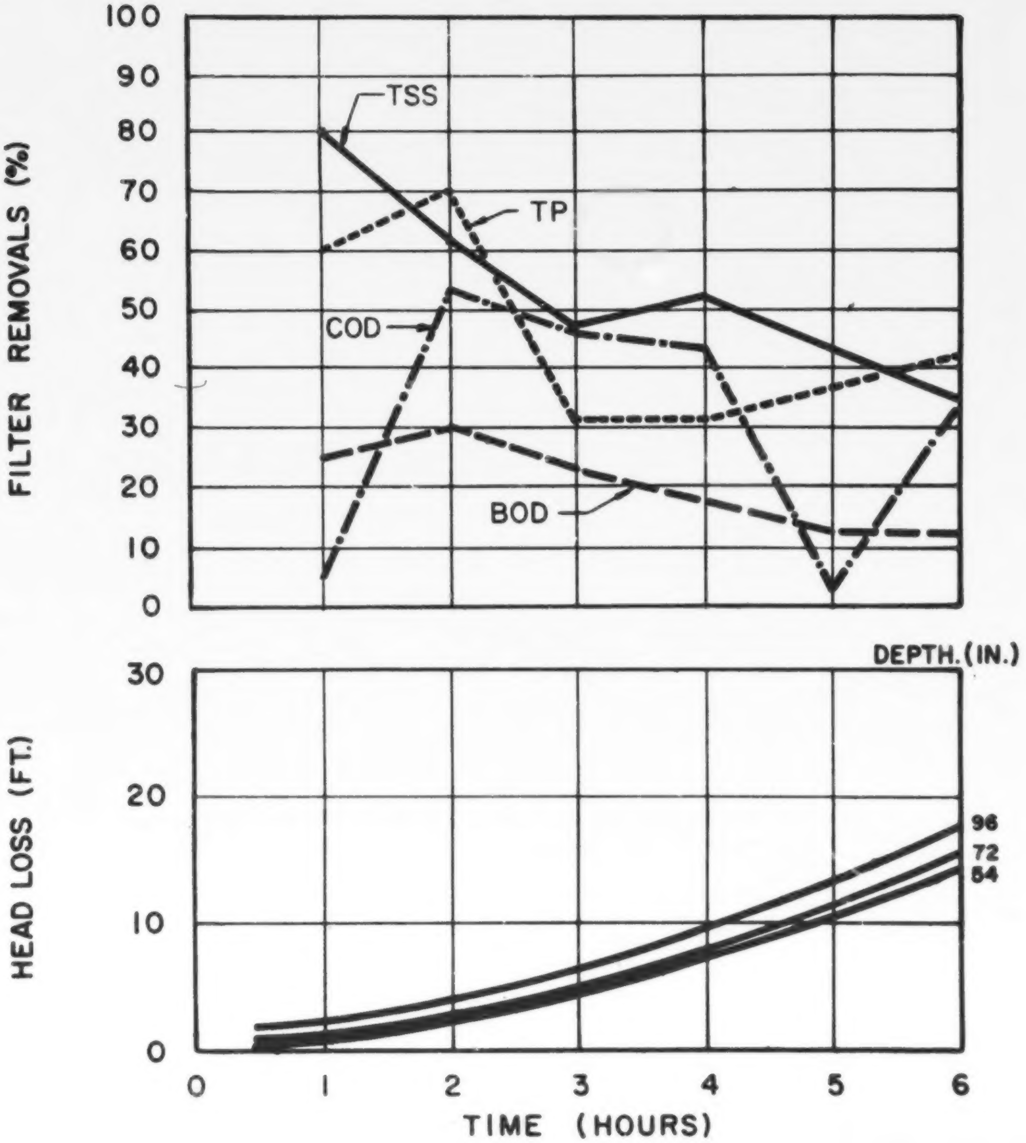
SCREEN 40 MESH. FILTER MEDIA 60 in. No. 3 ANTH./36 in. No. 612 SAND

DATE 6/22/71 FLUX RATE 16 gpm/ft² COAG. ALUM 30 mg/l

RUN No. 19BSFII POLY. 0 mg/l

**COMBINED SEWER OVERFLOW FILTRATION TEST**

**FIGURE C71**



SCREEN 40 MESH. FILTER MEDIA. 60 in. No. 3 ANTH./36 in. No. 612 SAND

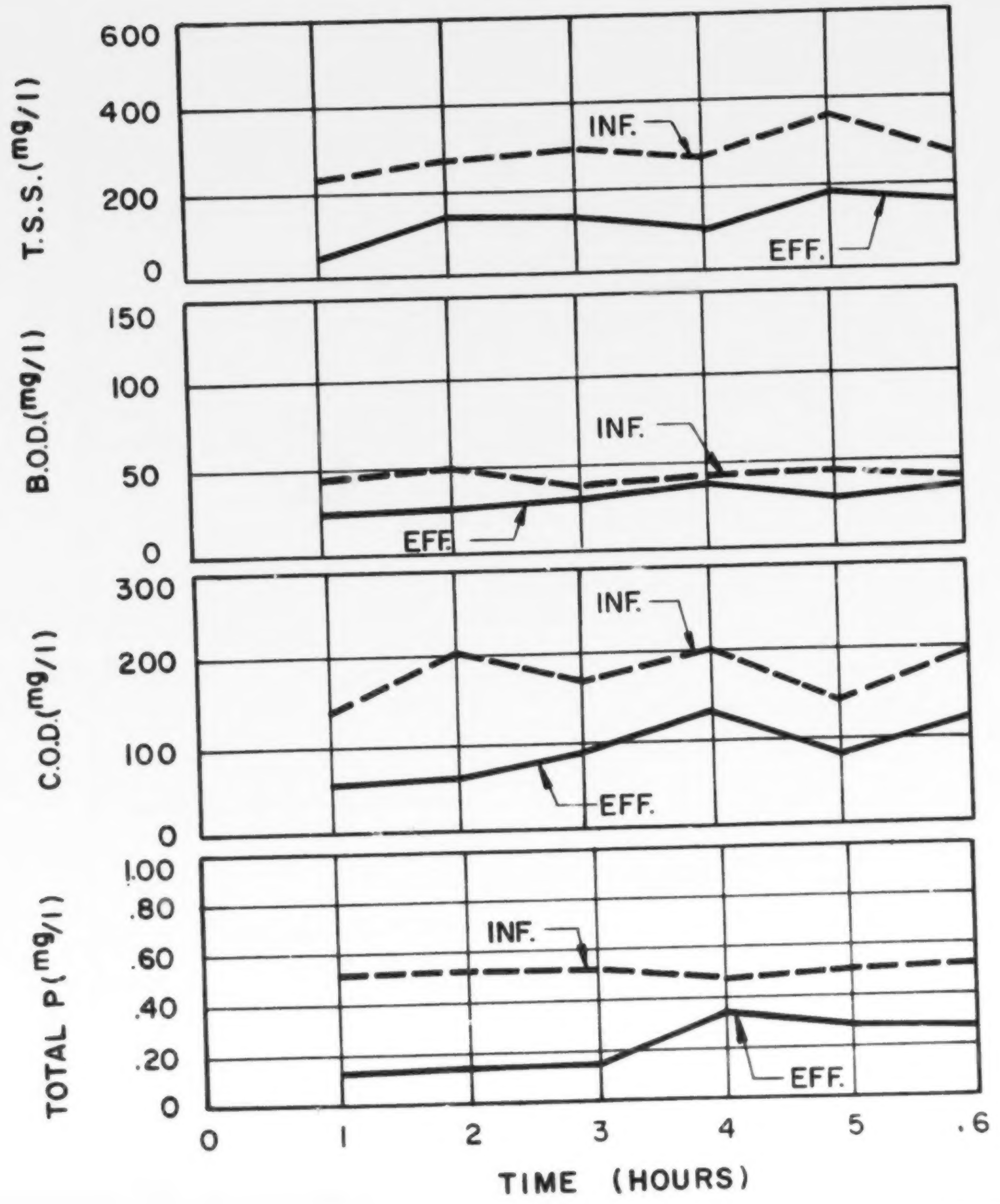
DATE 6/22/71 FLUX RATE 16 gpm/ft$^2$ COAG. ALUM 30 mg/l

POLY. 0 mg/l

RUN No. 19BSF11

COMBINED SEWER OVERFLOW FILTRATION TEST

FIGURE C 72



SCREEN 40 MESH. FILTER MEDIA 60 in. No. 3 ANTH./36 in. No. 612 SAND

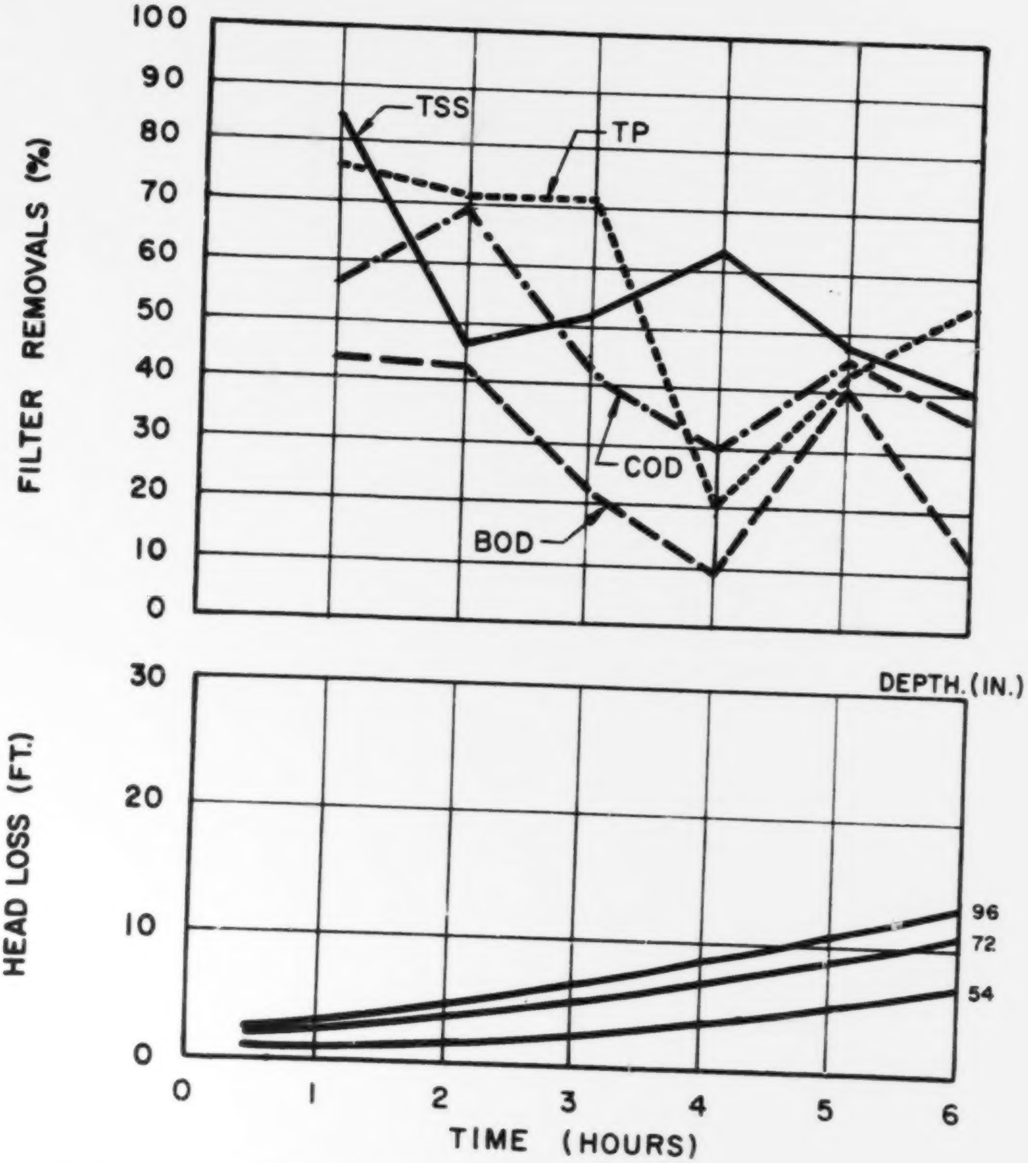
DATE 6/22/71 FLUX RATE 16 gpm/ft$^2$ COAG. ALUM. 30 mg/l

POLY. MAG. 560C 1.0 mg/l

RUN No. 19BSFIV

COMBINED SEWER OVERFLOW FILTRATION TEST

FIGURE C73



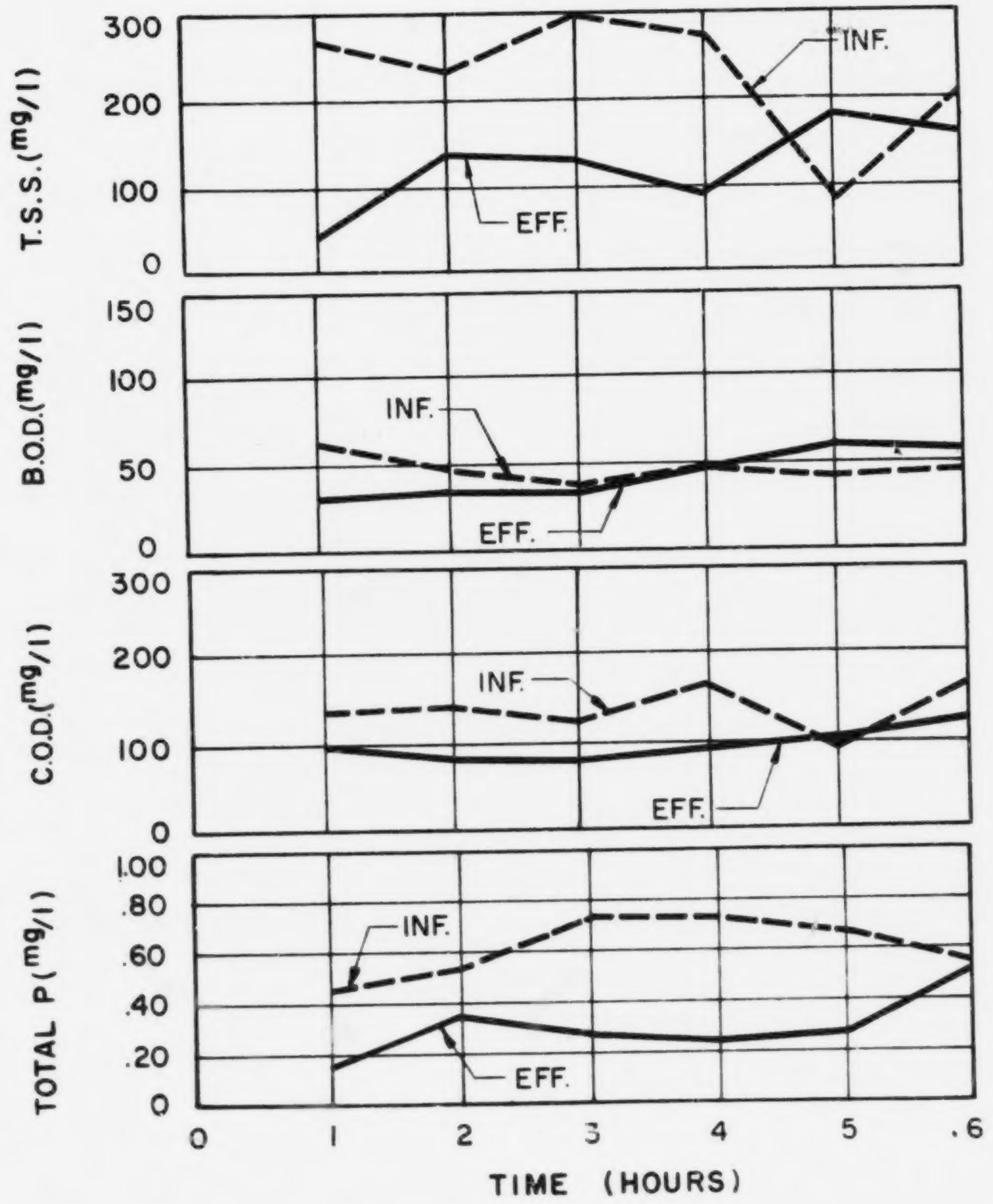
SCREEN 40 MESH. FILTER MEDIA 60 in. No. 3 ANTH./36 in. No. 612 SAND

DATE 6/22/71 FLUX RATE 16 gpm/ft² COAG. ALUM 30 mg/l

RUN No. 19BSFIV POLY. MAG.560 C 1.0 mg/l

COMBINED SEWER OVERFLOW FILTRATION TEST

FIGURE C74



SCREEN 40 MESH. FILTER MEDIA 60 in. No. 3 ANTH./36 in. No. 612 SAND

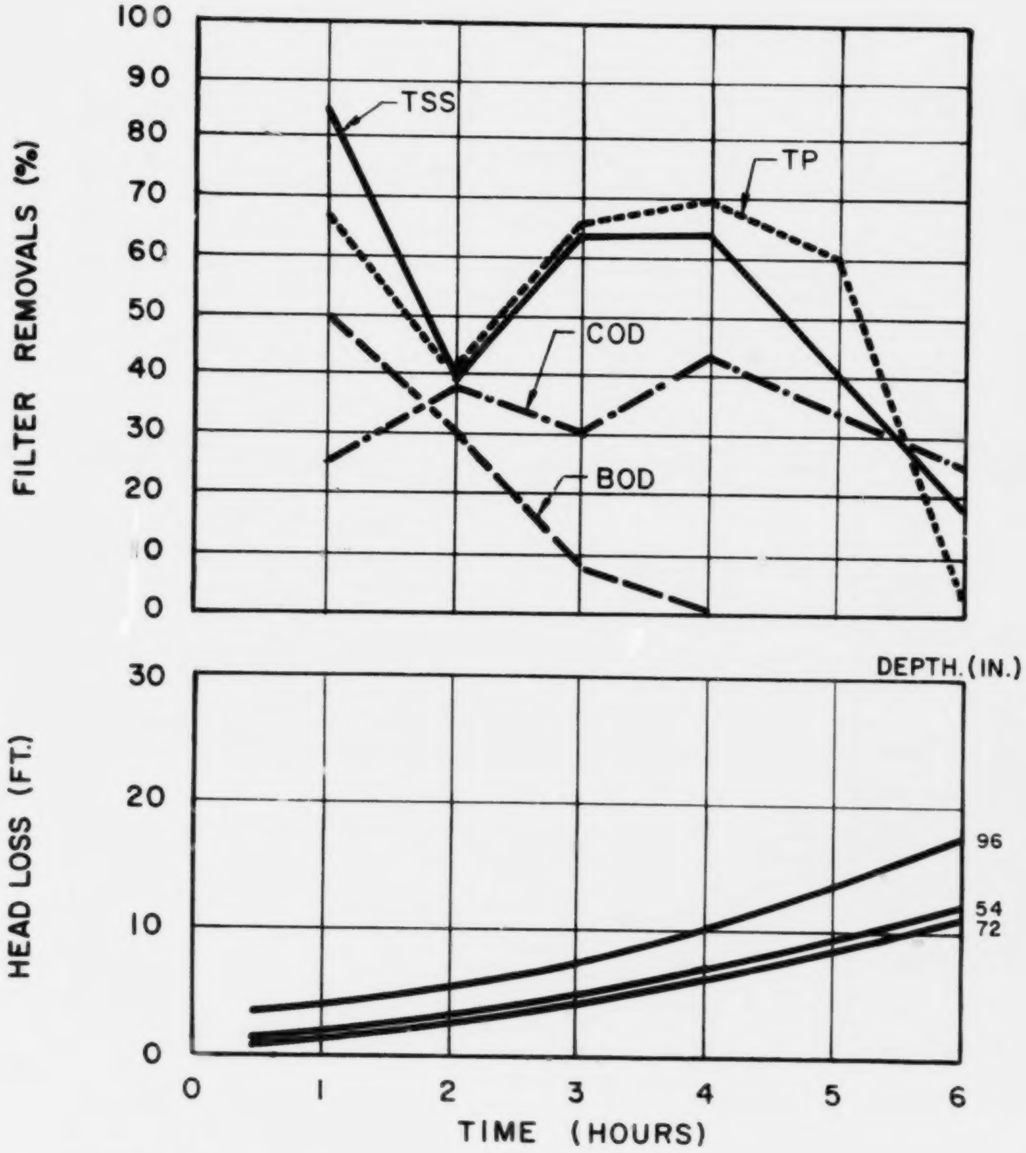
DATE 6/23/71 FLUX RATE 16 gpm/ft$^2$ COAG. ALUM. 30 mg/

POLY. HERC. 836 1.0 mg/

RUN No. 19CSFII

COMBINED SEWER OVERFLOW FILTRATION TEST

FIGURE C75



SCREEN 40 MESH. FILTER MEDIA 60 in. No. 3 ANTH./ 36 in. No. 612 SAND

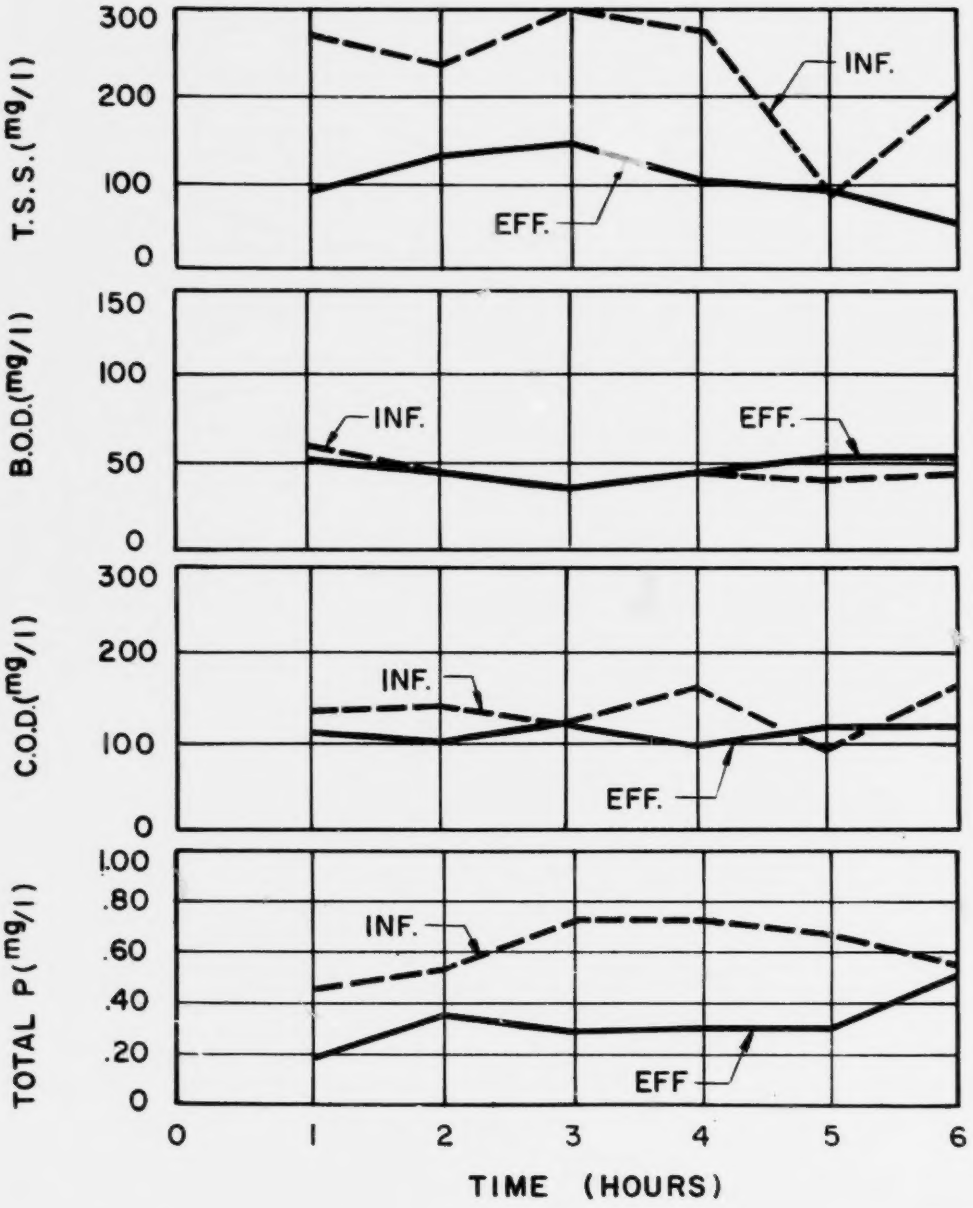
DATE 6/23/71 FLUX RATE 16 gpm/ft$^2$ COAG. ALUM 30 mg/l

POLY. HERC. 836 1.0 mg/l

RUN No. 19CSFII

COMBINED SEWER OVERFLOW FILTRATION TEST

FIGURE C76



SCREEN 40 MESH. FILTER MEDIA 60 in. No. 3 ANTH./36 in. No. 612 SAND

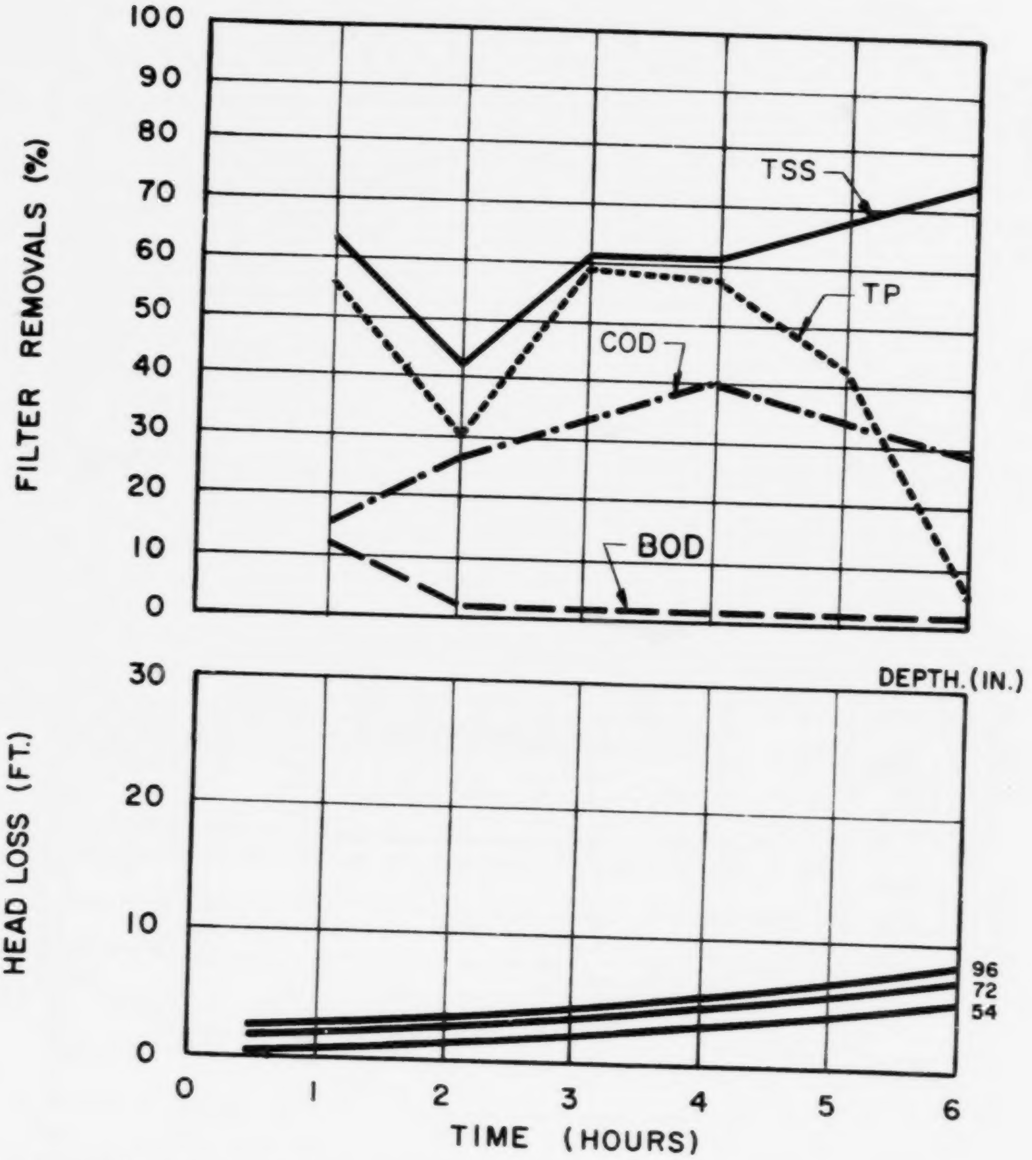
DATE 6/23/71 FLUX RATE 16 gpm/ft$^2$ COAG. Fe $Cl_3$ 15 mg/l

POLY. HERC. 836 1.0 mg/l

RUN No. 19CSFIV

COMBINED SEWER OVERFLOW FILTRATION TEST

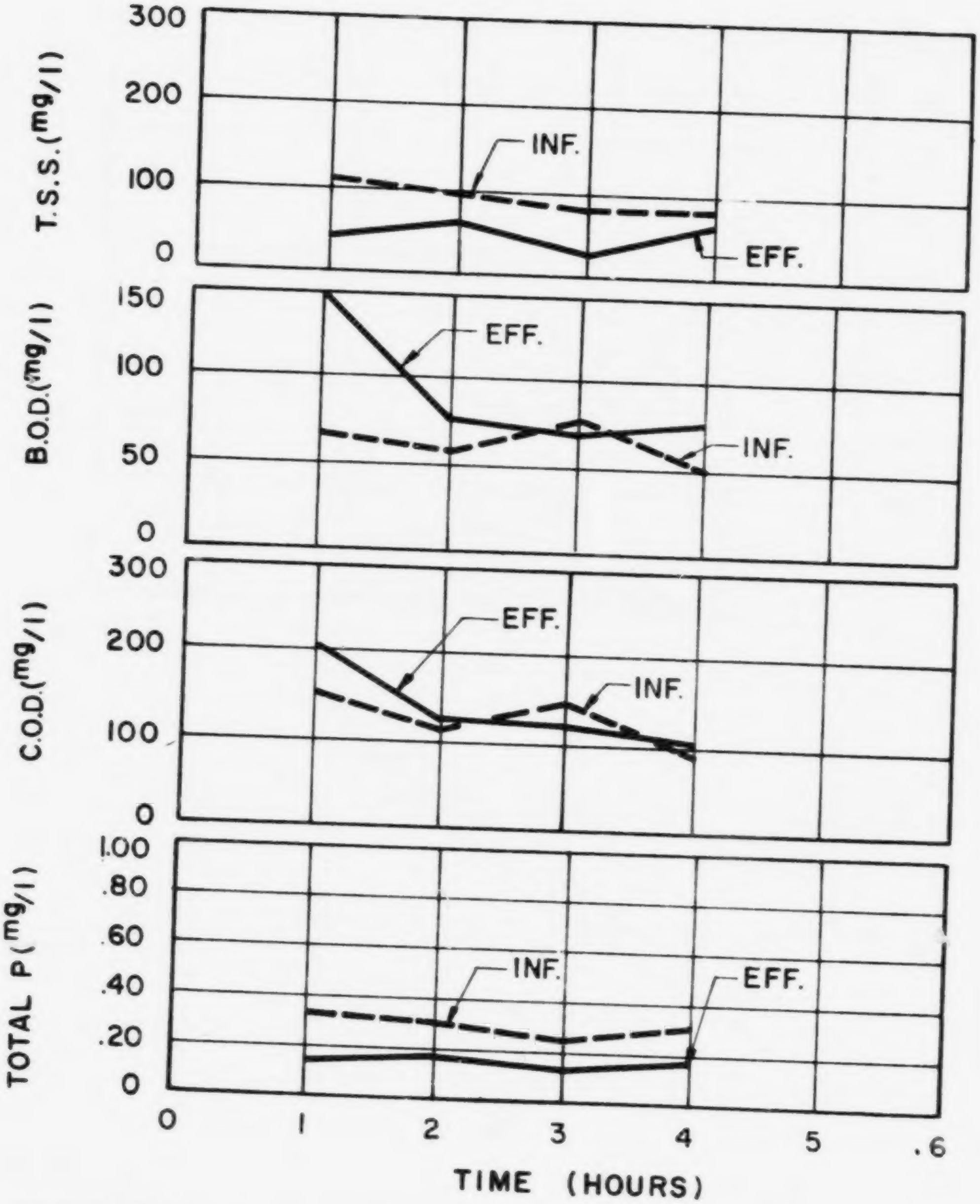
FIGURE C77



SCREEN 40 MESH. FILTER MEDIA 60 in. No. 3 ANTH./ 36 in. No. 612 SAND
DATE 6/23/71 FLUX RATE 16 gpm/ft$^2$ COAG. Fe Cl$_3$ 15 mg/l
RUN No. 19CSF1V POLY. HERC. 836 1.0 mg/l

COMBINED SEWER OVERFLOW FILTRATION TEST

FIGURE C78



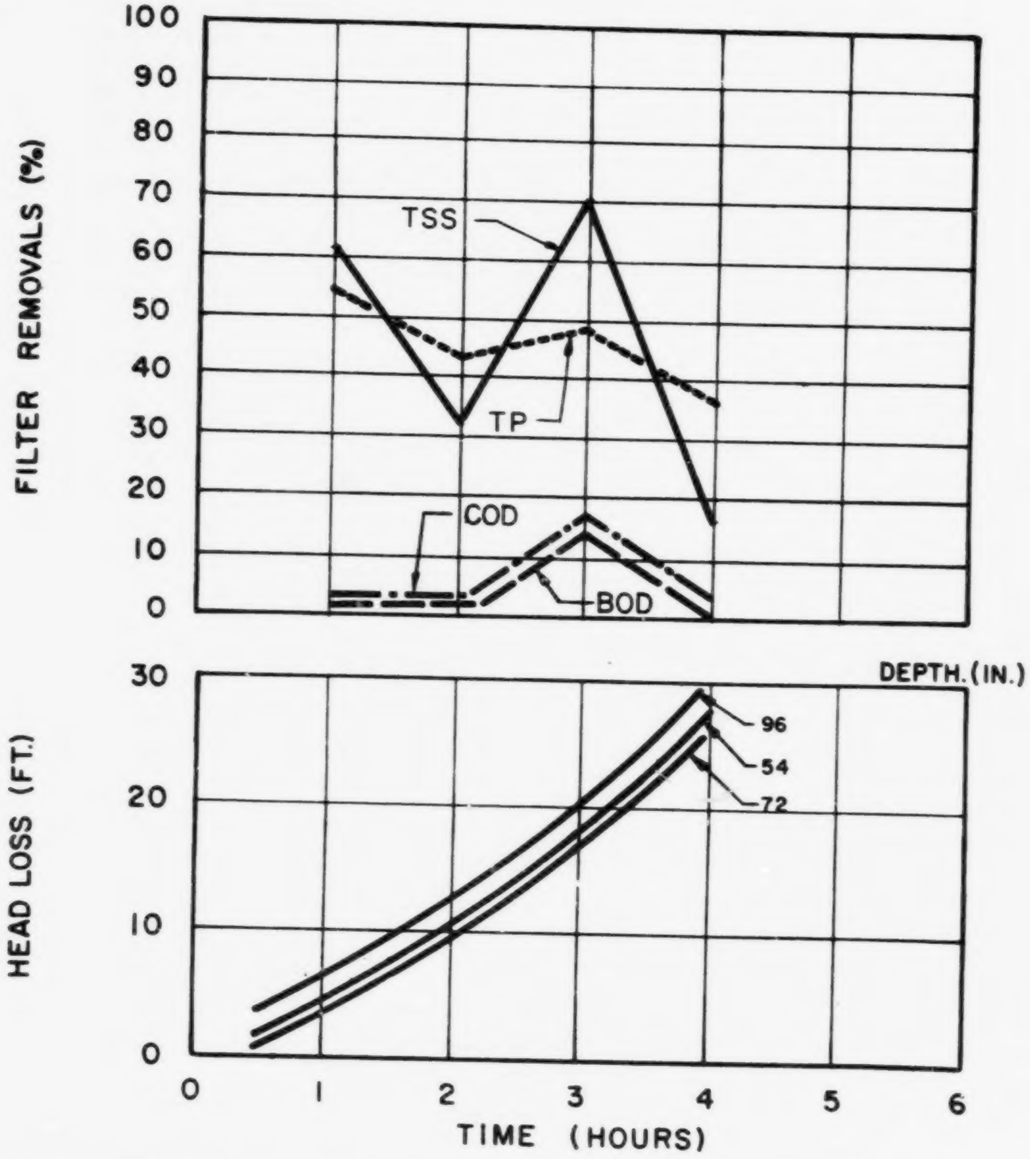
SCREEN 40 MESH. FILTER MEDIA 60 in. No. 3 ANTH./36 in. No. 612 SAND

DATE 6/29/71 FLUX RATE 24 gpm/ft$^2$ COAG. $FeCl_3$ 25 mg/l

RUN No. 20SF11 POLY. ATLA. 4A4 1.0 mg/l

COMBINED SEWER OVERFLOW FILTRATION TEST

FIGURE C79



SCREEN 40 MESH. FILTER MEDIA 60 in. No. 3 ANTH./36 in. No. 612 SAND

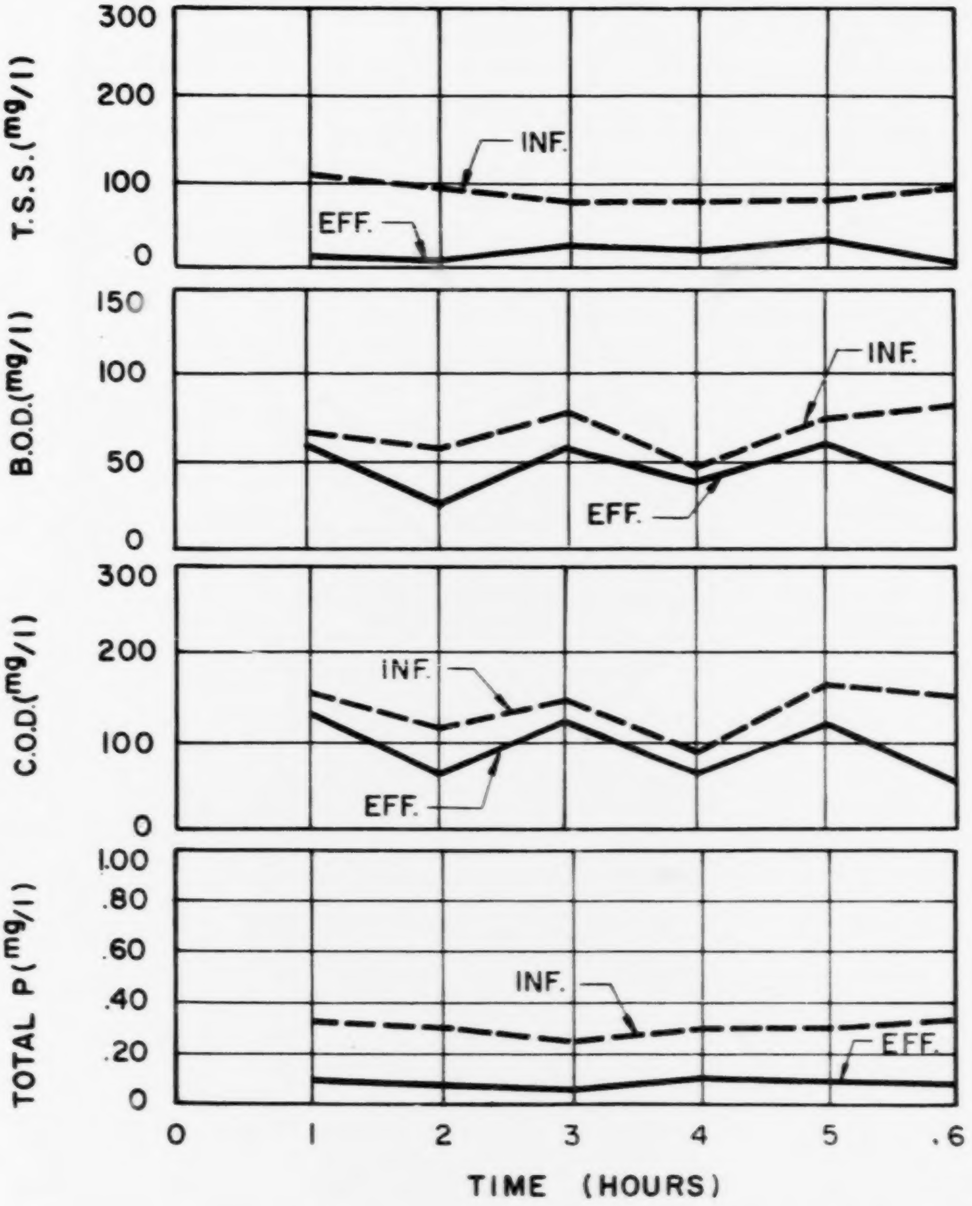
DATE 6/29/71 FLUX RATE 24 gpm/ft$^2$ COAG. FeCl3 25 mg/l

POLY. ATLA 4A41.0 mg/l

RUN No. 20SF11

## COMBINED SEWER OVERFLOW FILTRATION TEST

FIGURE C80



SCREEN 40 MESH. FILTER MEDIA 60 in. No. 3 ANTH./36 in. No. 612 SAND

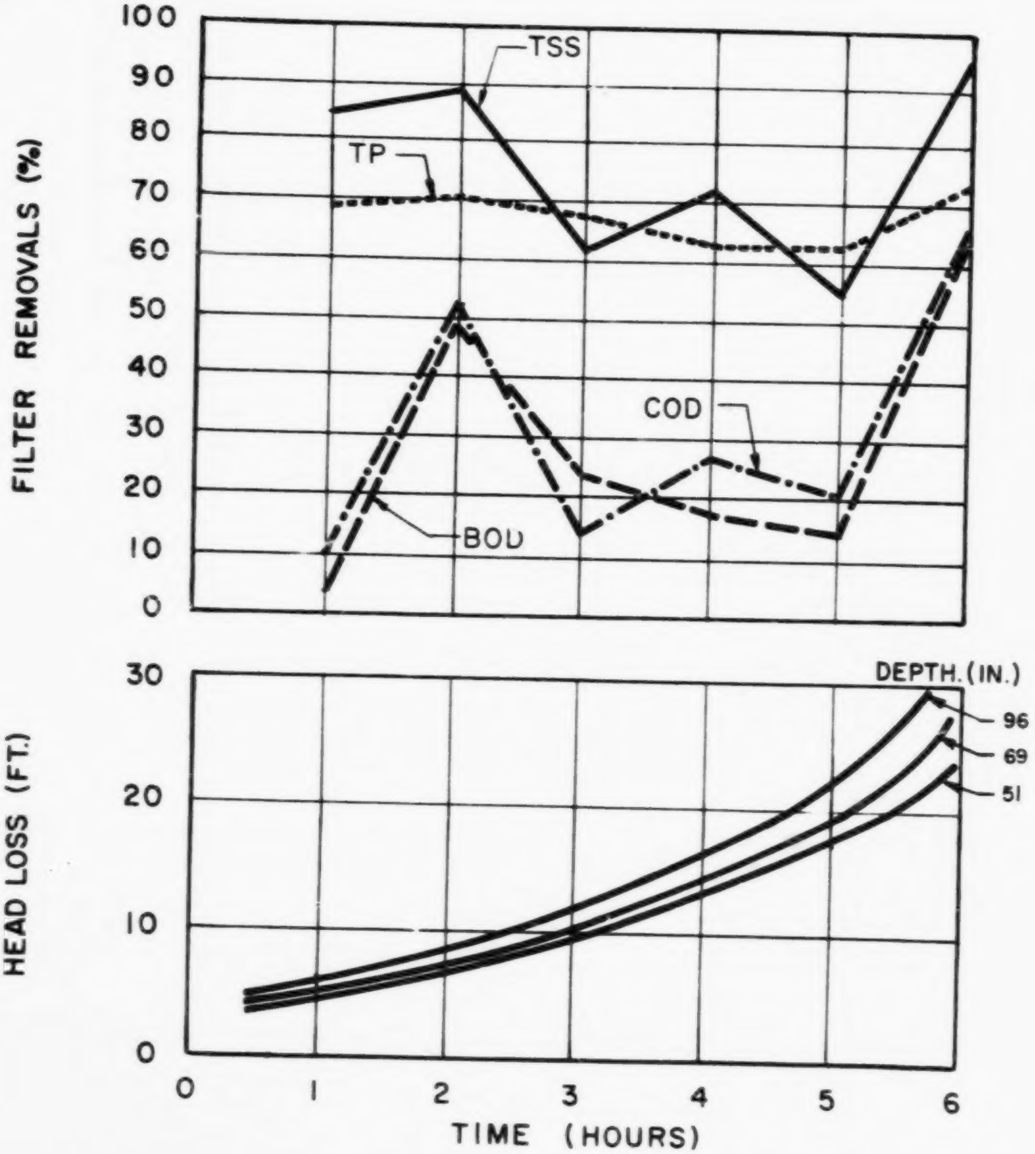
DATE 6/29/71 FLUX RATE 16 gpm/ft$^2$ COAG. FeCl$_3$ 25 mg/l

POLY. ATLA. 4A4 1.0 mg/l

RUN No. 20SFIII

**COMBINED SEWER OVERFLOW FILTRATION TEST**

FIGURE C81



SCREEN 40 MESH. FILTER MEDIA 60 in. No. 3 ANTH./36 in. No. 612 SAND

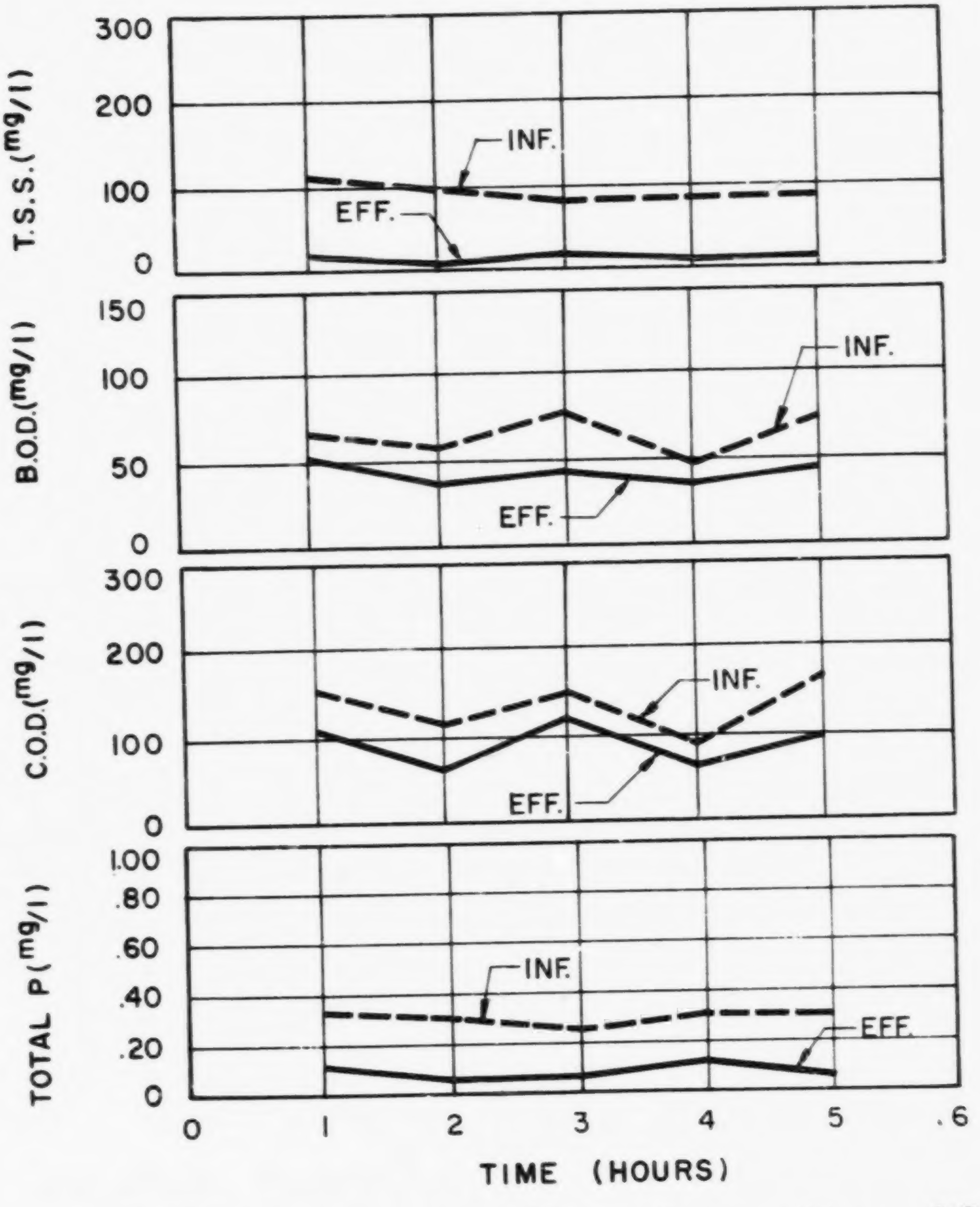
DATE 6/29/71 FLUX RATE 16 gpm/ft² COAG. FeCl3 25 mg/l

POLY. ATLA. 4A4 1.0 mg/l

RUN No. 20SFIII

COMBINED SEWER OVERFLOW FILTRATION TEST

FIGURE C82



SCREEN 40 MESH. FILTER MEDIA 60 in. No. 3 ANTH. / 36 in. No. 612 SAND

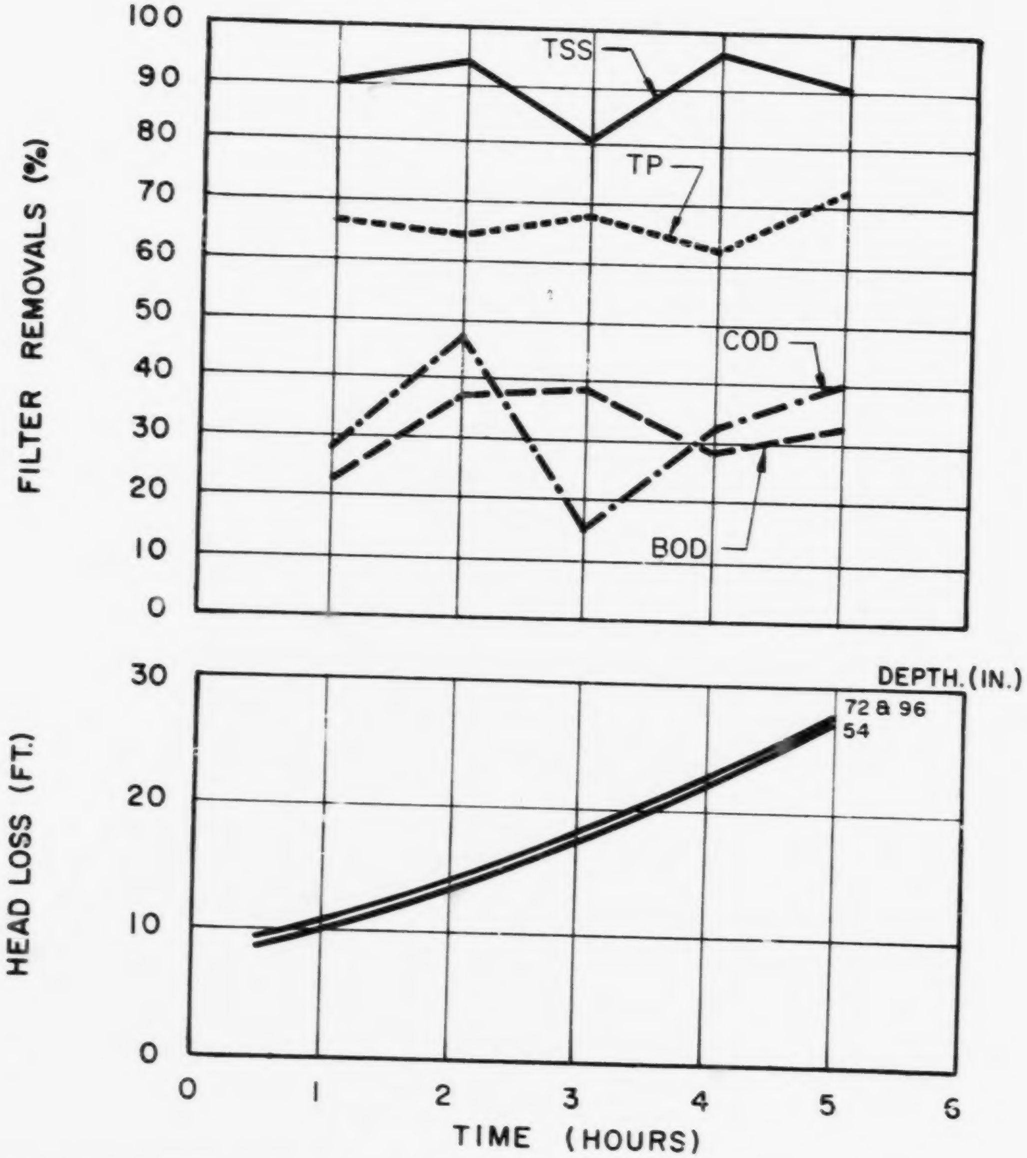
DATE 6/29/71 FLUX RATE 8 gpm/ft$^2$ COAG. Fe Cl3 25 mg/l

POLY. ATLA. 4A4 mg/l

RUN No. 20SFIV

**COMBINED SEWER OVERFLOW FILTRATION TEST**

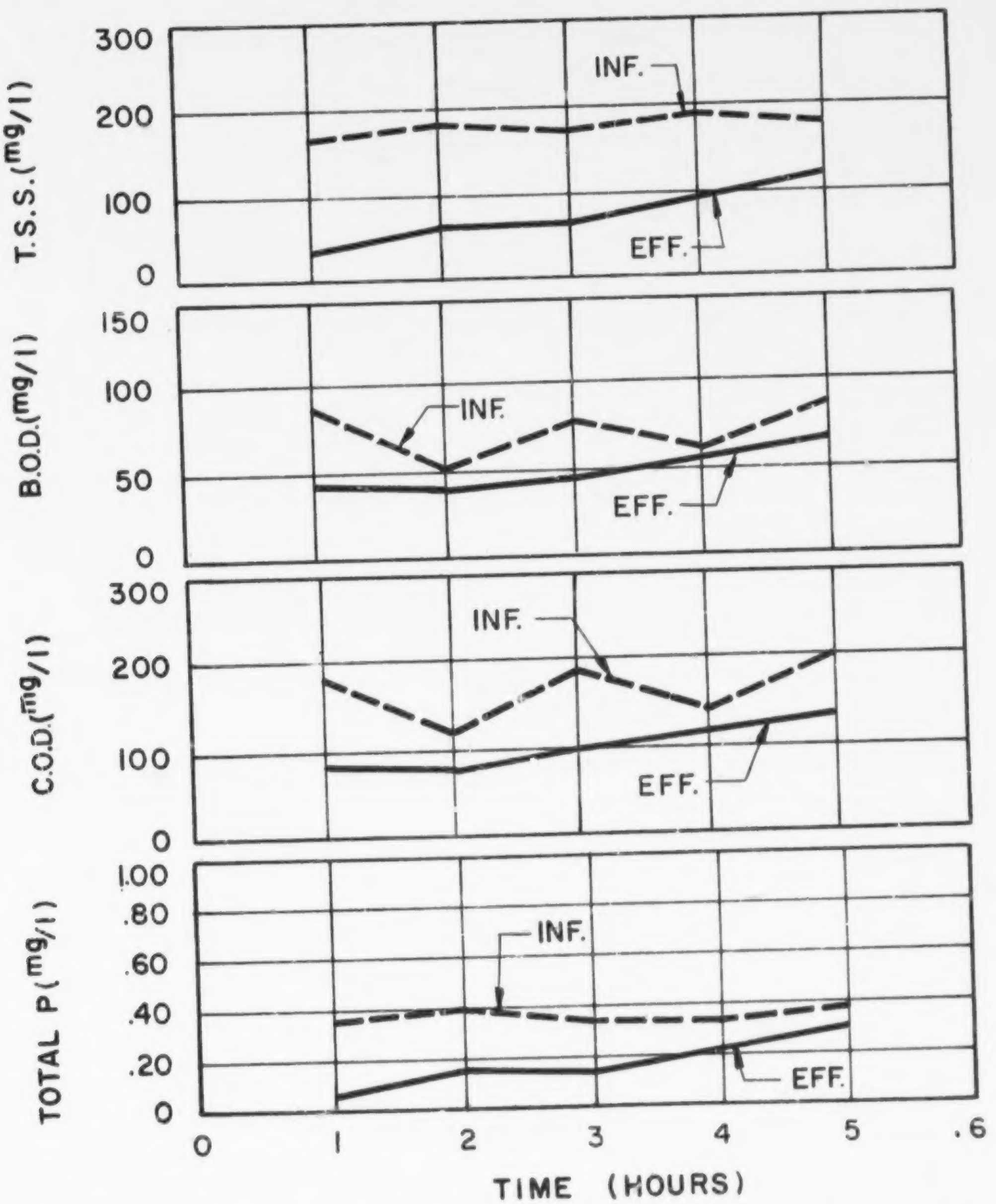
FIGURE C83



SCREEN 40 MESH. FILTER MEDIA 60 in. No. 3 ANTH./36 in. No. 612 SAND
DATE 6/29/71 FLUX RATE 8 gpm/ft$^2$ COAG. $FeCL_3$ 25 mg/l
RUN No. 20SFIV POLY. ATLA. 4A4 1.0 mg/l

COMBINED SEWER OVERFLOW FILTRATION TEST

FIGURE C84



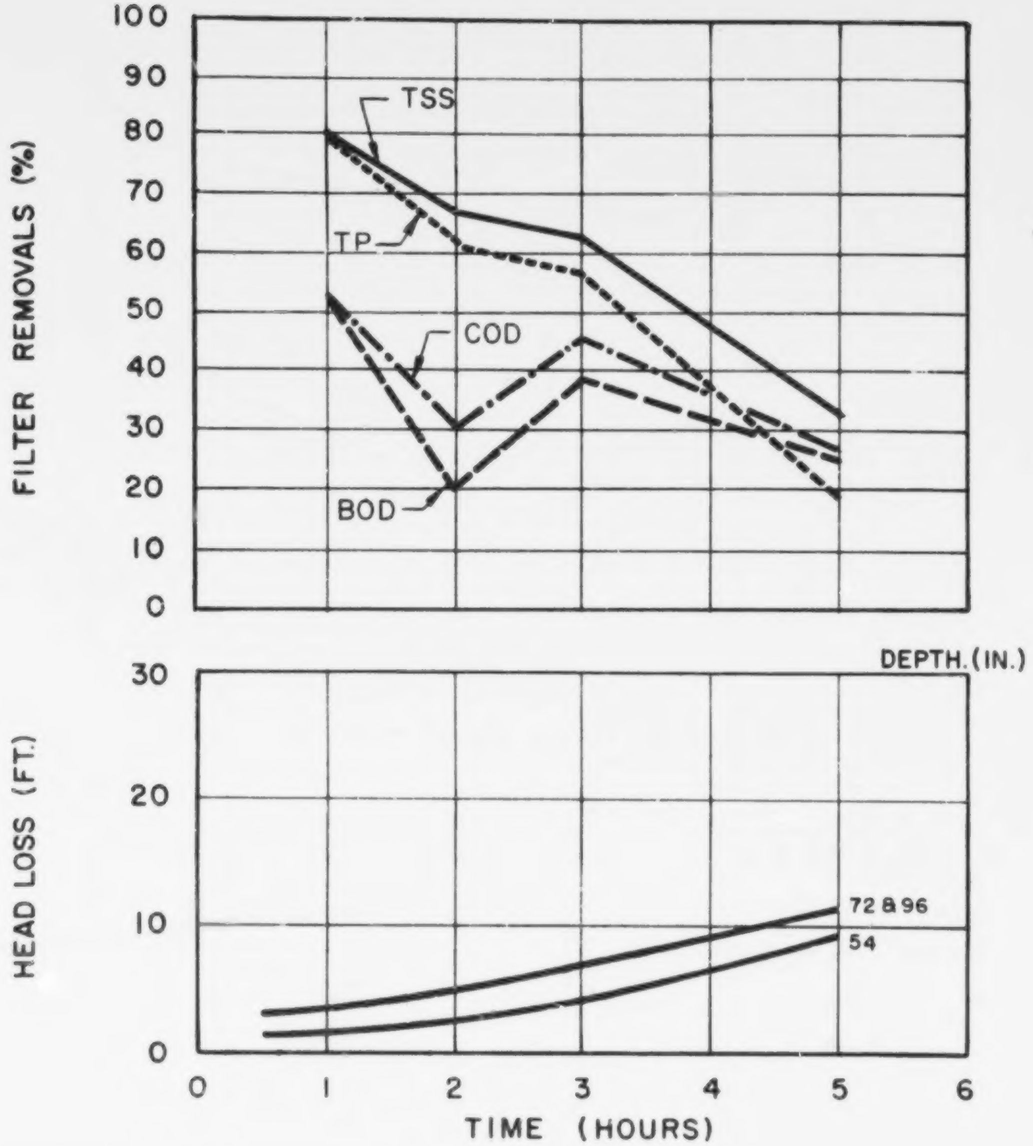
SCREEN 40 MESH. FILTER MEDIA 60 in. No. 3 ANTH./36 in. No. 612 SAND

DATE 6/30/71 FLUX RATE 16 gpm/ft$^2$ COAG. ALUM. 30 mg/l
POLY. ATLA. 4A4 1.0 mg/l

RUN No. 20ASFII

**COMBINED SEWER OVERFLOW FILTRATION TEST**

FIGURE C85



SCREEN 40 MESH. FILTER MEDIA 60 in. No. 3 ANTH./36 in. No. 612 SAND

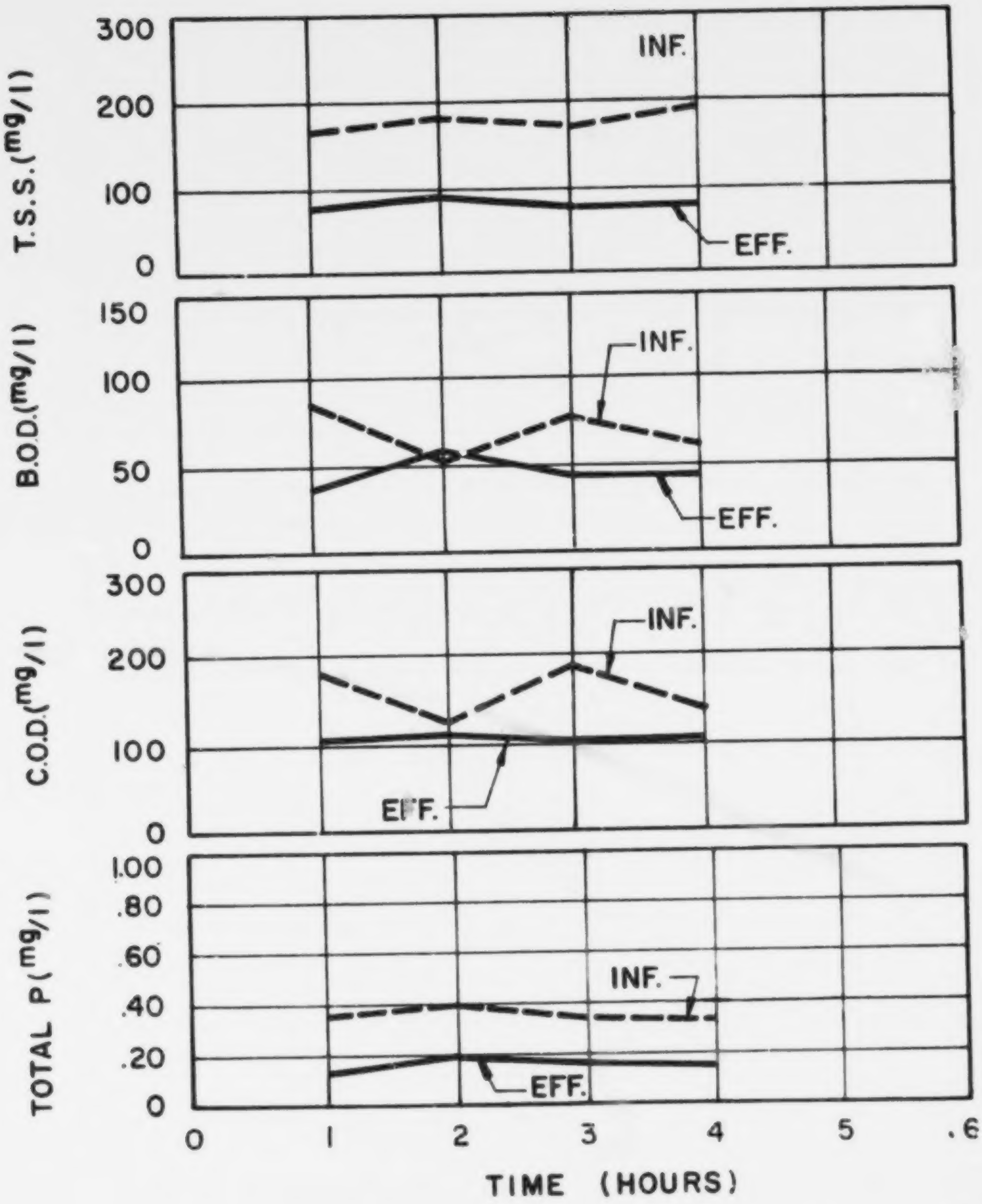
DATE 6/30/71 FLUX RATE 16 gpm/ft$^2$ COAG. ALUM 30 mg/l

POLY. ATLA 4A4 1.0 mg/l

RUN No. 20ASFII

COMBINED SEWER OVERFLOW FILTRATION TEST

FIGURE C86



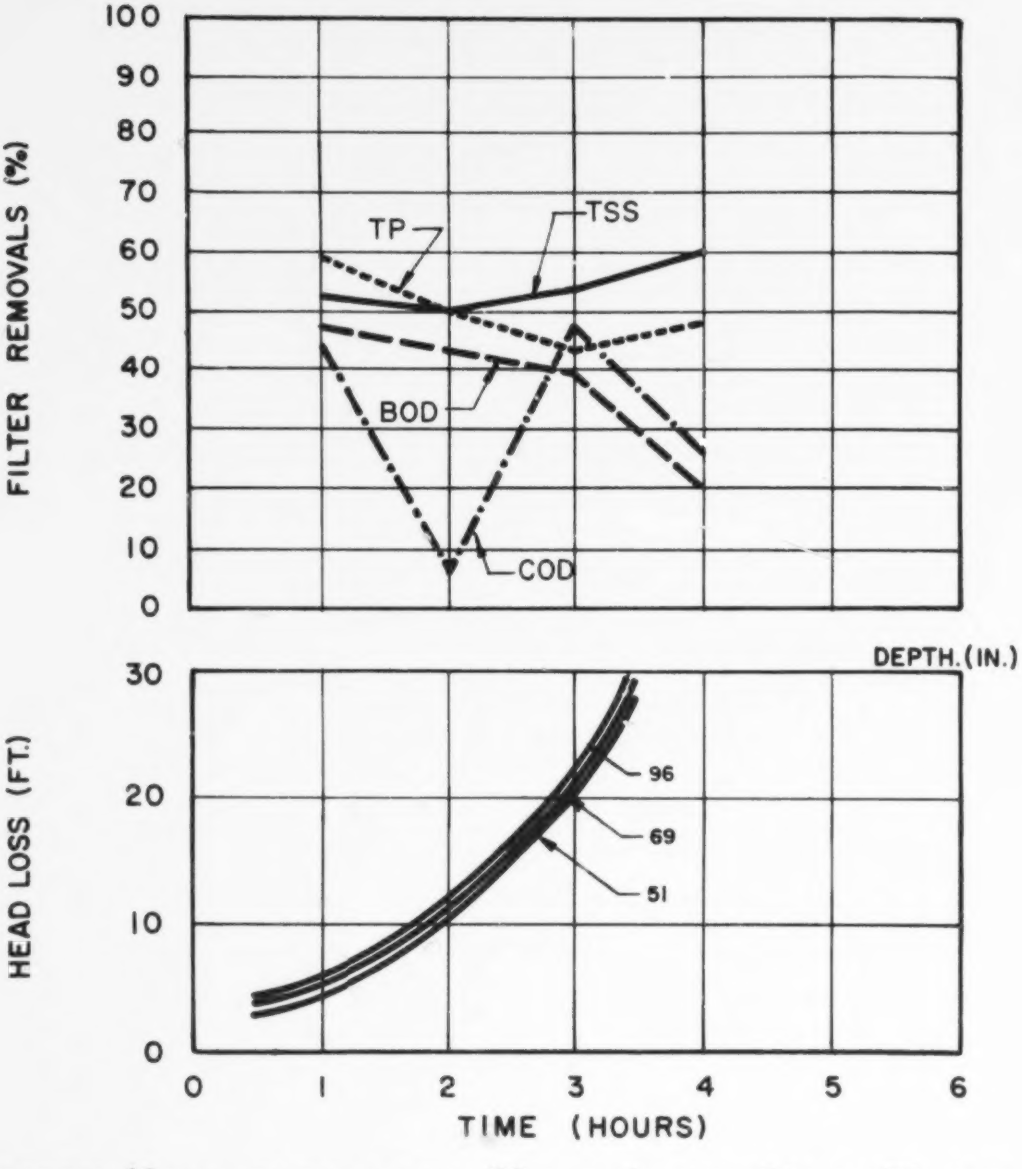
SCREEN 40 MESH. FILTER MEDIA 60 in. No. 3 ANTH./36 in. No. 612 SAND

DATE 6/30/71 FLUX RATE 16 gpm/ft² COAG. ALUM. 30 mg/l
POLY. ATLA. 4A4 1.0 mg/l

RUN No. 20ASFIII

COMBINED SEWER OVERFLOW FILTRATION TEST

FIGURE C87



SCREEN 40 MESH. FILTER MEDIA. 60 in. No. 3 ANTH./ 36 in. No. 612 SAND

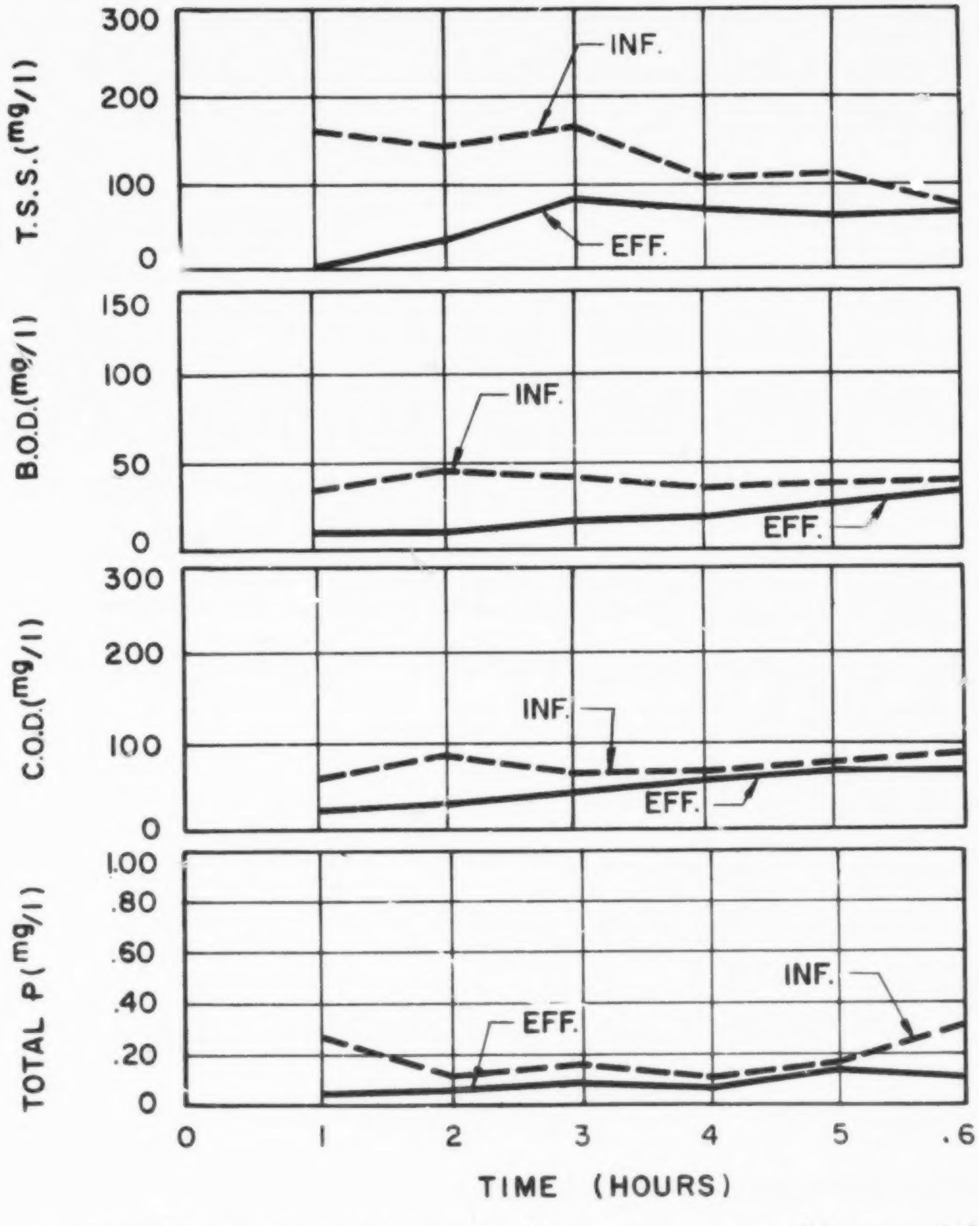
DATE 6/30/71 FLUX RATE 16 gpm/ft$^2$ COAG. ALUM 30 mg/l

POLY. ATLA 4A4 1.0 mg/l

RUN No. 20ASFIII

COMBINED SEWER OVERFLOW FILTRATION TEST

FIGURE C88



SCREEN 40 MESH. FILTER MEDIA 60 in. No. 3 ANTH./36 in. No. 612 SAND

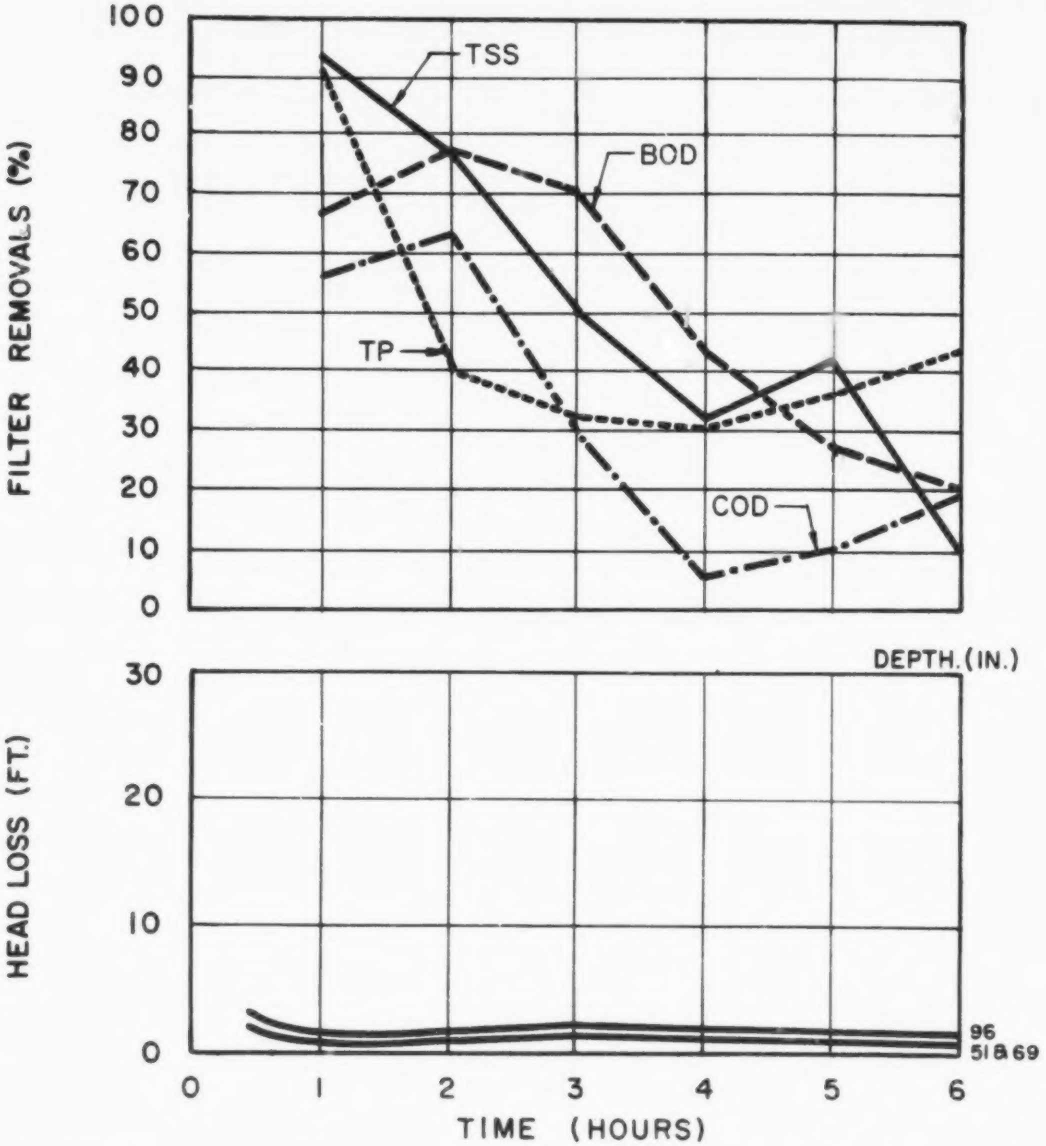
DATE 7/11/71 FLUX RATE 8 gpm/ft$^2$ COAG. ALUM. 30 mg/l

POLY. SWIFT X-400 1.0 mg/l

RUN No. 21SFIII

COMBINED SEWER OVERFLOW FILTRATION TEST

FIGURE C89



SCREEN 40 MESH. FILTER MEDIA. 60 in. No. 3 ANTH./36 in. No. 612 SAND

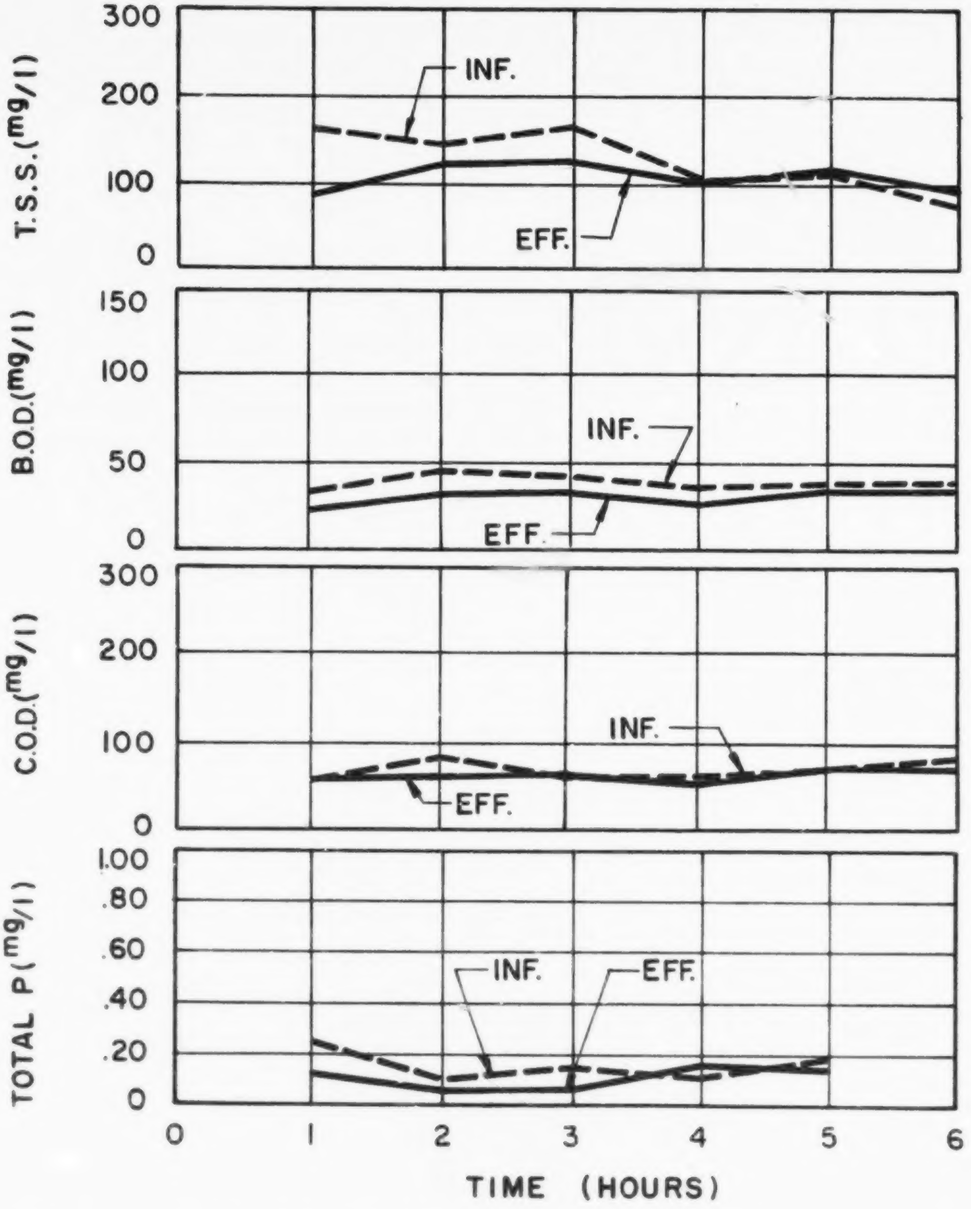
DATE 7/11/71 FLUX RATE 8 gpm/ft² COAG. ALUM 30 mg/l

POLY SWIFT X-400 1.0 mg/l

RUN No. 21SFIII

COMBINED SEWER OVERFLOW FILTRATION TEST

FIGURE C90



SCREEN 40 MESH. FILTER MEDIA 60 in. No. 3 ANTH./36 in. No. 612 SAND

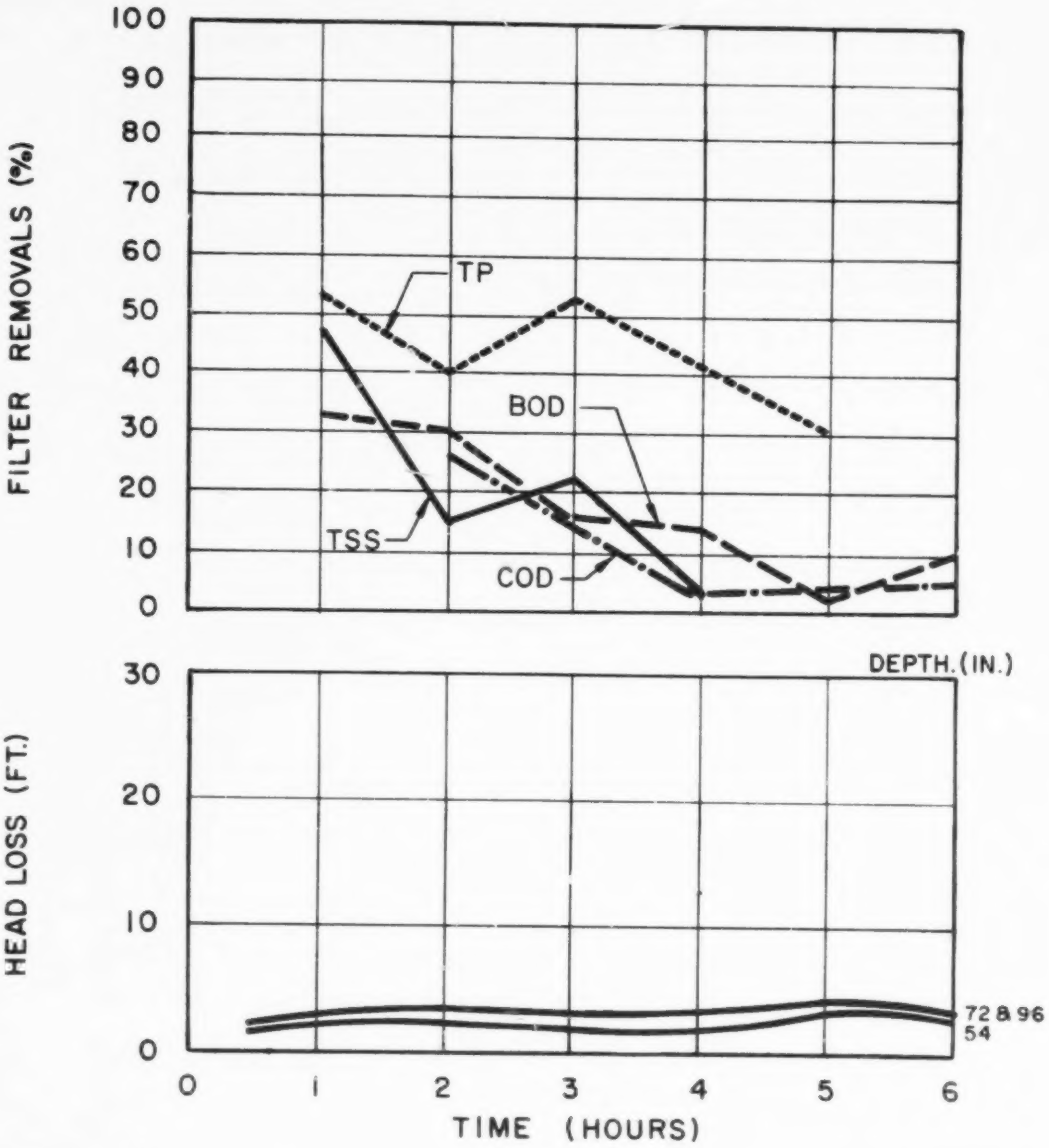
DATE 7/11/71 FLUX RATE 16 gpm/ft$^2$ COAG. ALUM 30 mg/l

POLY. SWIFT X-400 1.0 mg/l

RUN No. 21SF1V

**COMBINED SEWER OVERFLOW FILTRATION TEST**

FIGURE C91



SCREEN 40 MESH. FILTER MEDIA. 60 in. No. 3 ANTH./36 in. No. 612 SAND

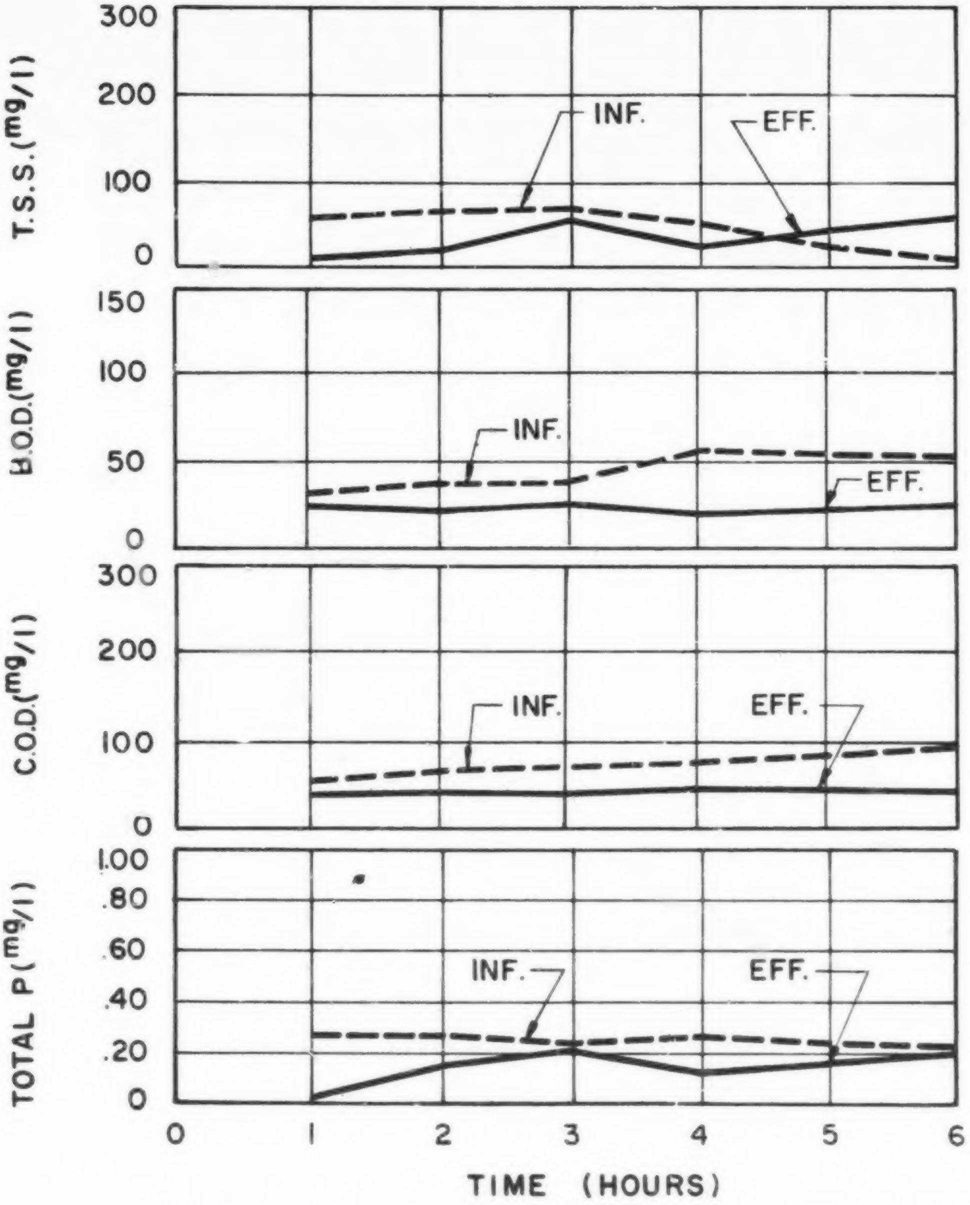
DATE 7/11/71 FLUX RATE 16 gpm/ft² COAG. ALUM 30 mg/l

POLY. SWIFT X-400 1.0 mg/l

RUN No. 21SFIV

COMBINED SEWER OVERFLOW FILTRATION TEST

FIGURE C92



SCREEN 40 MESH. FILTER MEDIA 60 in. No. 3 ANTH./36 in. No. 612 SAND

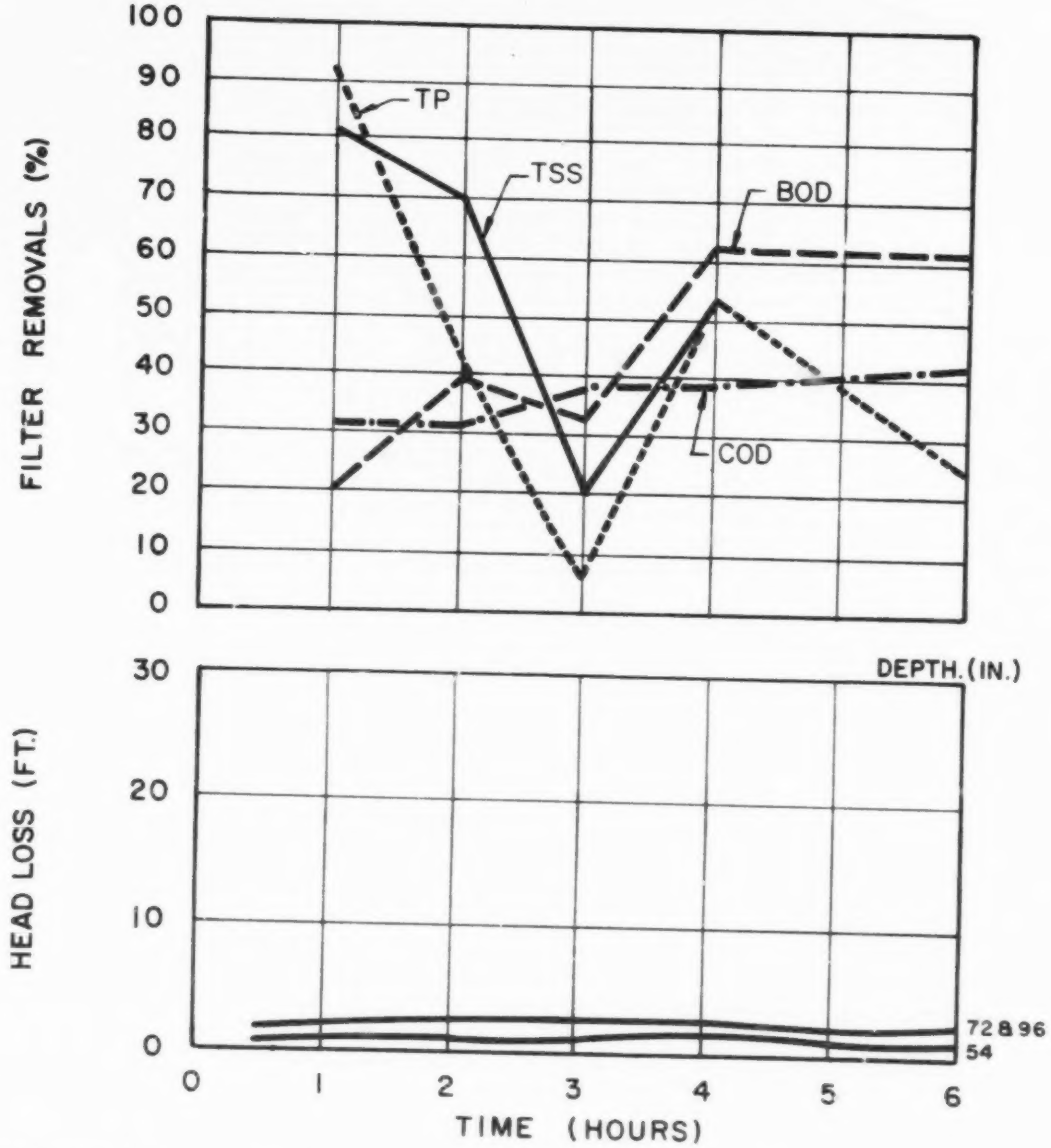
DATE 7/13/71 FLUX RATE 8 gpm/ft$^2$ COAG. ALUM 50 mg/l

POLY. SWIFT X-400 1.0 mg/l

RUN No. 21ASFII

COMBINED SEWER OVERFLOW FILTRATION TEST

FIGURE C93



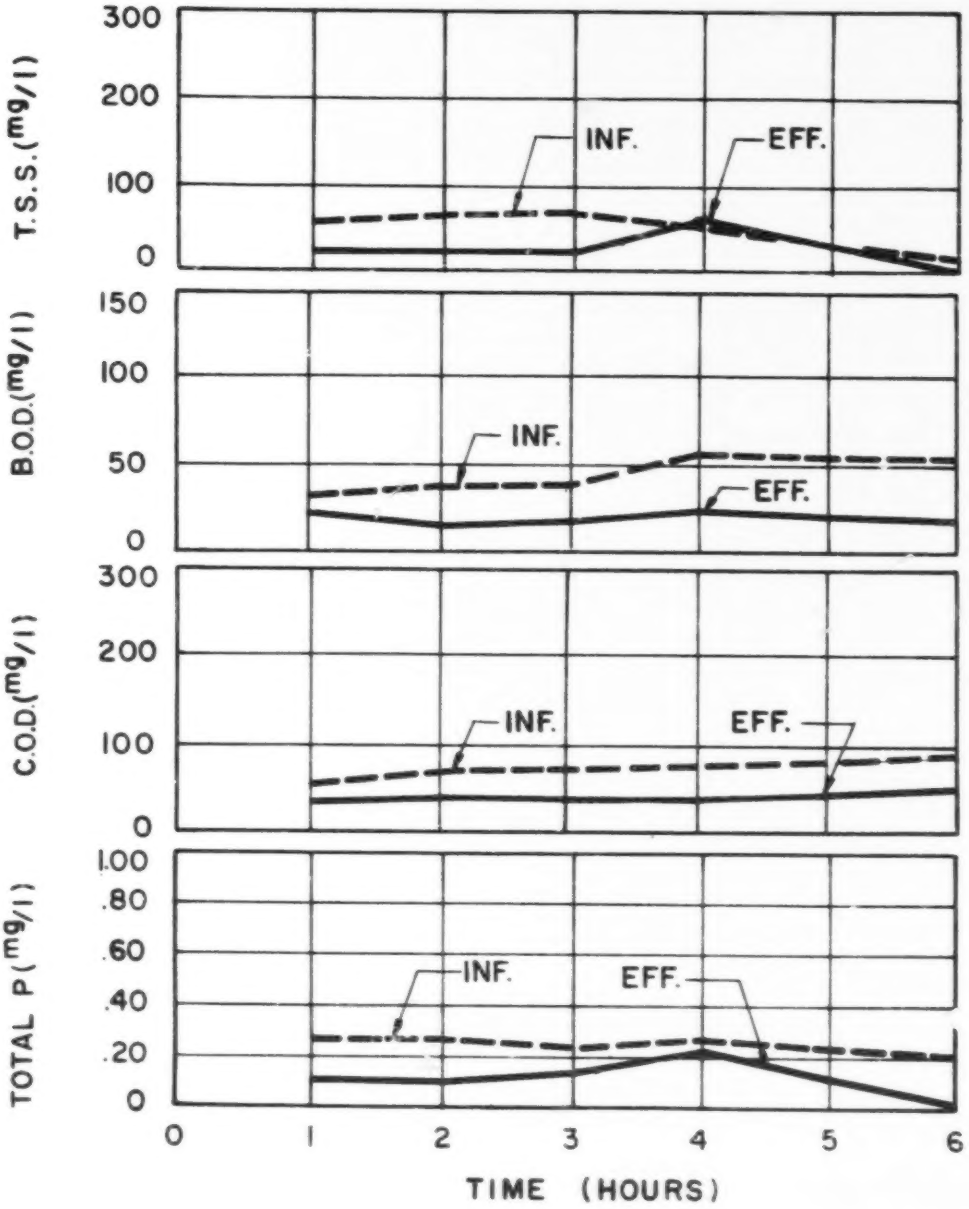
SCREEN 40 MESH. FILTER MEDIA 60 in. No. 3 ANTH./36 in. No. 612 SAND

DATE 7/13/71 FLUX RATE 8 gpm/ft$^2$ COAG. ALUM 50 mg/l

RUN No. 21ASF11 POLY. SWIFT X-400 1.0 mg/l

COMBINED SEWER OVERFLOW FILTRATION TEST

FIGURE C94



SCREEN 40 MESH. FILTER MEDIA 60 in. No. 3 ANTH./36 in. No. 612 SAND

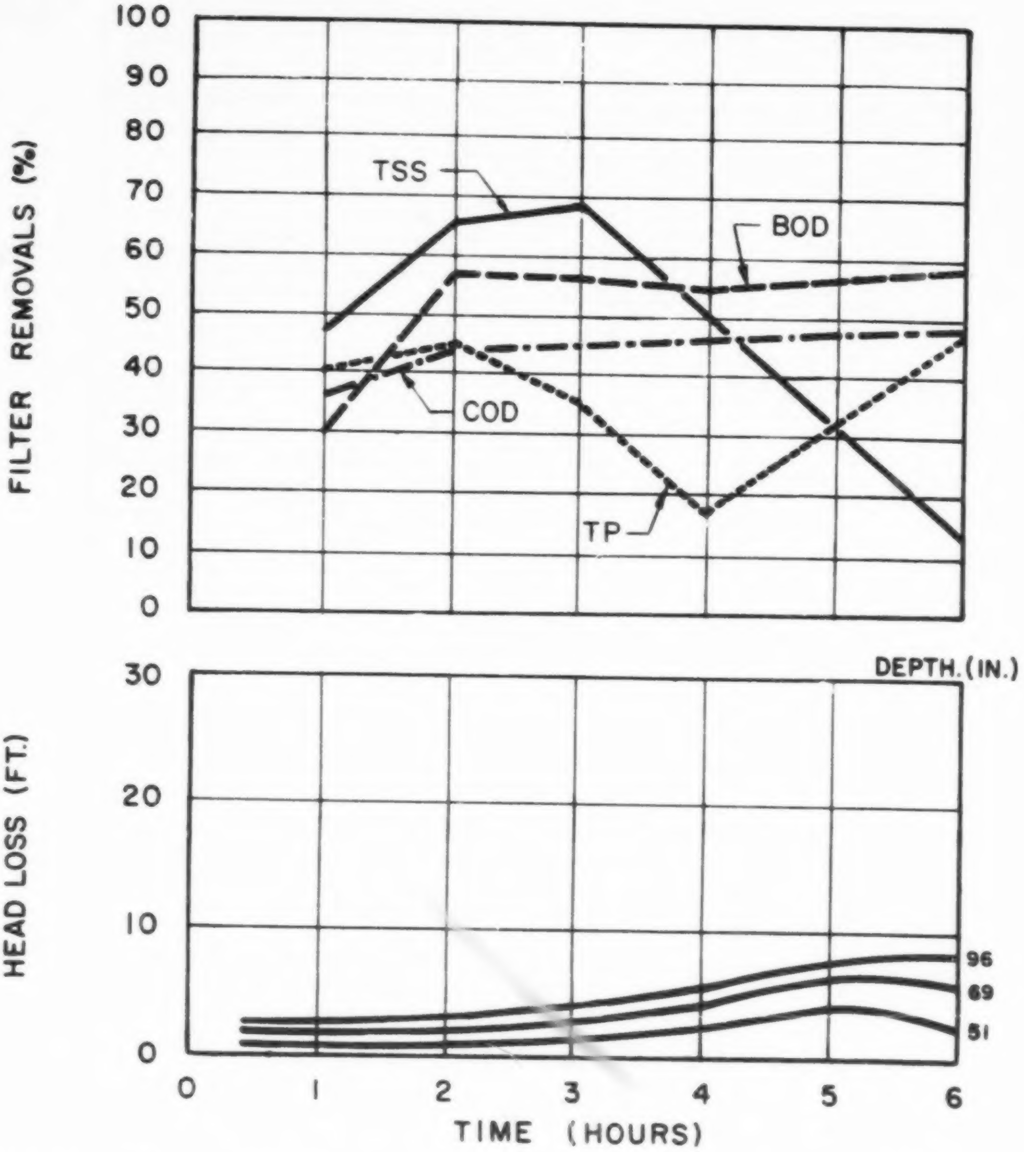
DATE 7/13/71 FLUX RATE 24 gpm/ft$^2$ COAG. ALUM. 30 mg/l

POLY. SWIFT X-400 1.0 mg/l

RUN No. 21ASFIII

COMBINED SEWER OVERFLOW FILTRATION TEST

FIGURE C95



SCREEN 40 MESH. FILTER MEDIA. 60 in. No. 3 ANTH./36 in. No. 612 SAND

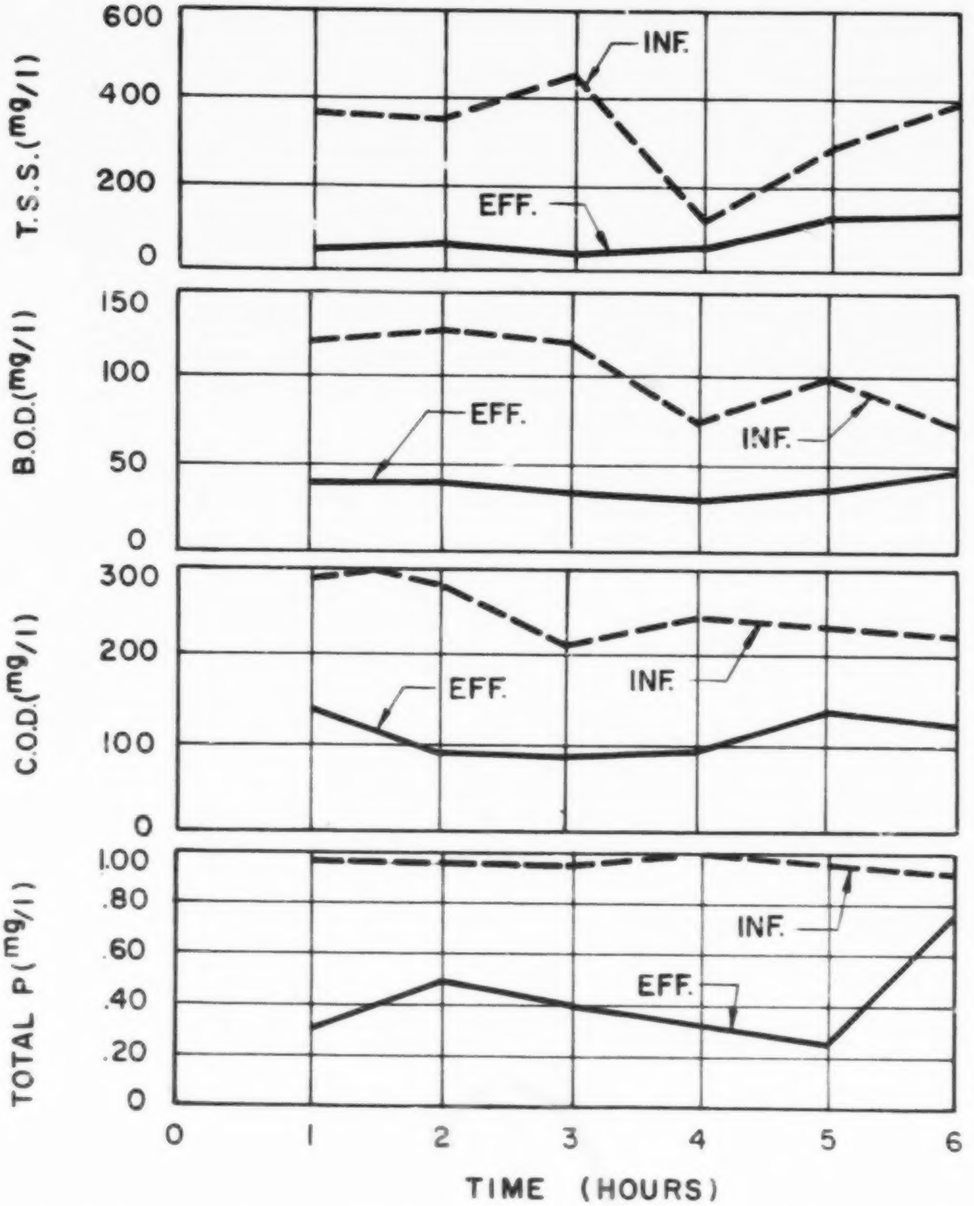
DATE 7/13/71 FLUX RATE 24 gpm/ft² COAG. ALUM 30 mg/l

POLY. SWIFT X-400 1.0 mg/l

RUN No. 21ASF III

COMBINED SEWER OVERFLOW FILTRATION TEST

FIGURE C96



SCREEN 40 MESH. FILTER MEDIA 60 in. No. 3 ANTH./36 in. No. 612 SAND

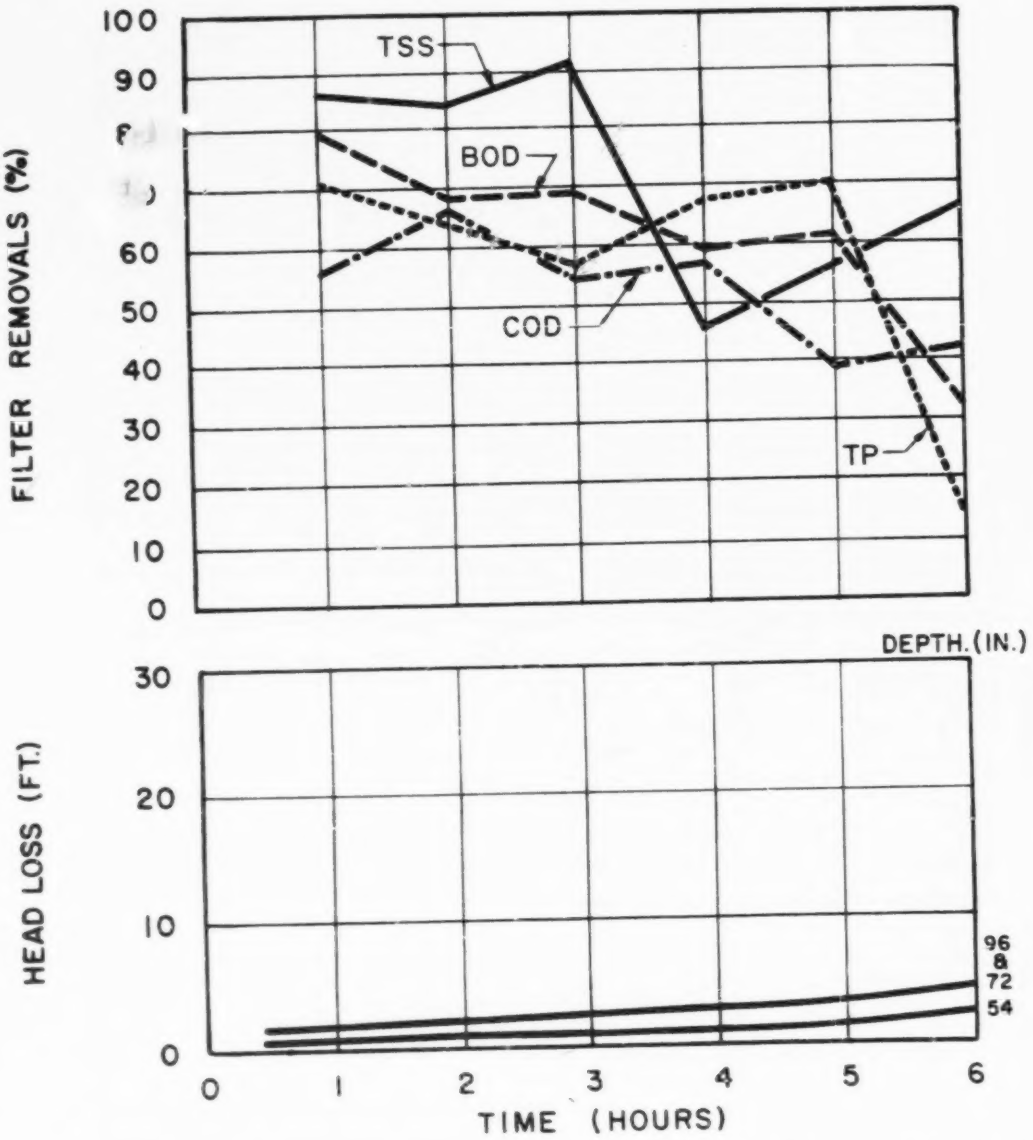
DATE 7/19/71 FLUX RATE 8 gpm/ft$^2$ COAG. ALUM. 30 mg/l

POLY. SWIFT X-400 1.0 mg/l

RUN No. 22 SFII

COMBINED SEWER OVERFLOW FILTRATION TEST

FIGURE C97



SCREEN 40 MESH. FILTER MEDIA 60 in. No. 3 ANTH./36 in. No. 612 SAND

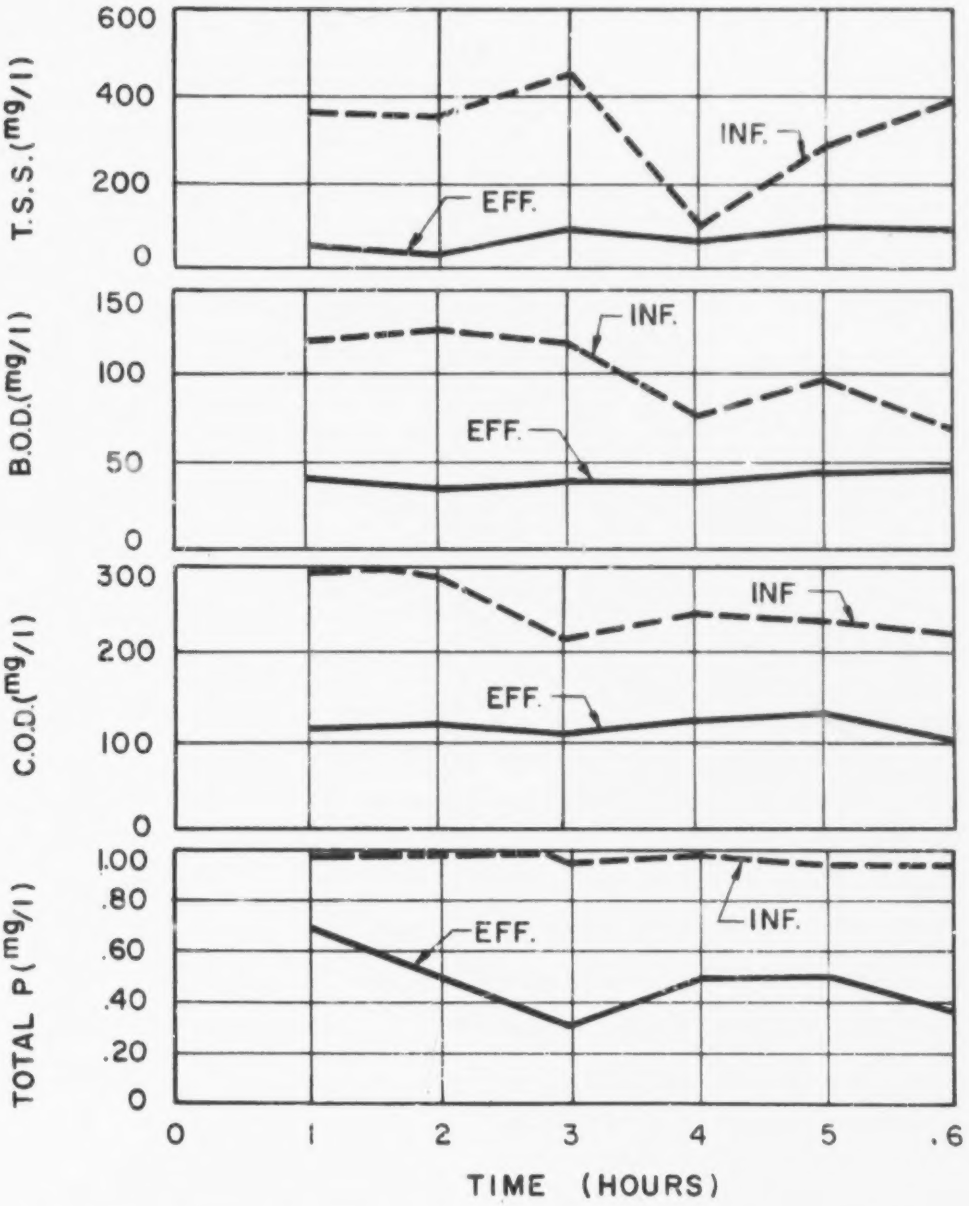
DATE 7/19/71 FLUX RATE 8 gpm/ft² COAG. ALUM 30 mg/l

POLY SWIFT X-400 1.0 mg/l

RUN No. 22SF11

## COMBINED SEWER OVERFLOW FILTRATION TEST

FIGURE C98



SCREEN 40 MESH. FILTER MEDIA 60 in. No. 3 ANTH./ 36 in. No. 612 SAND

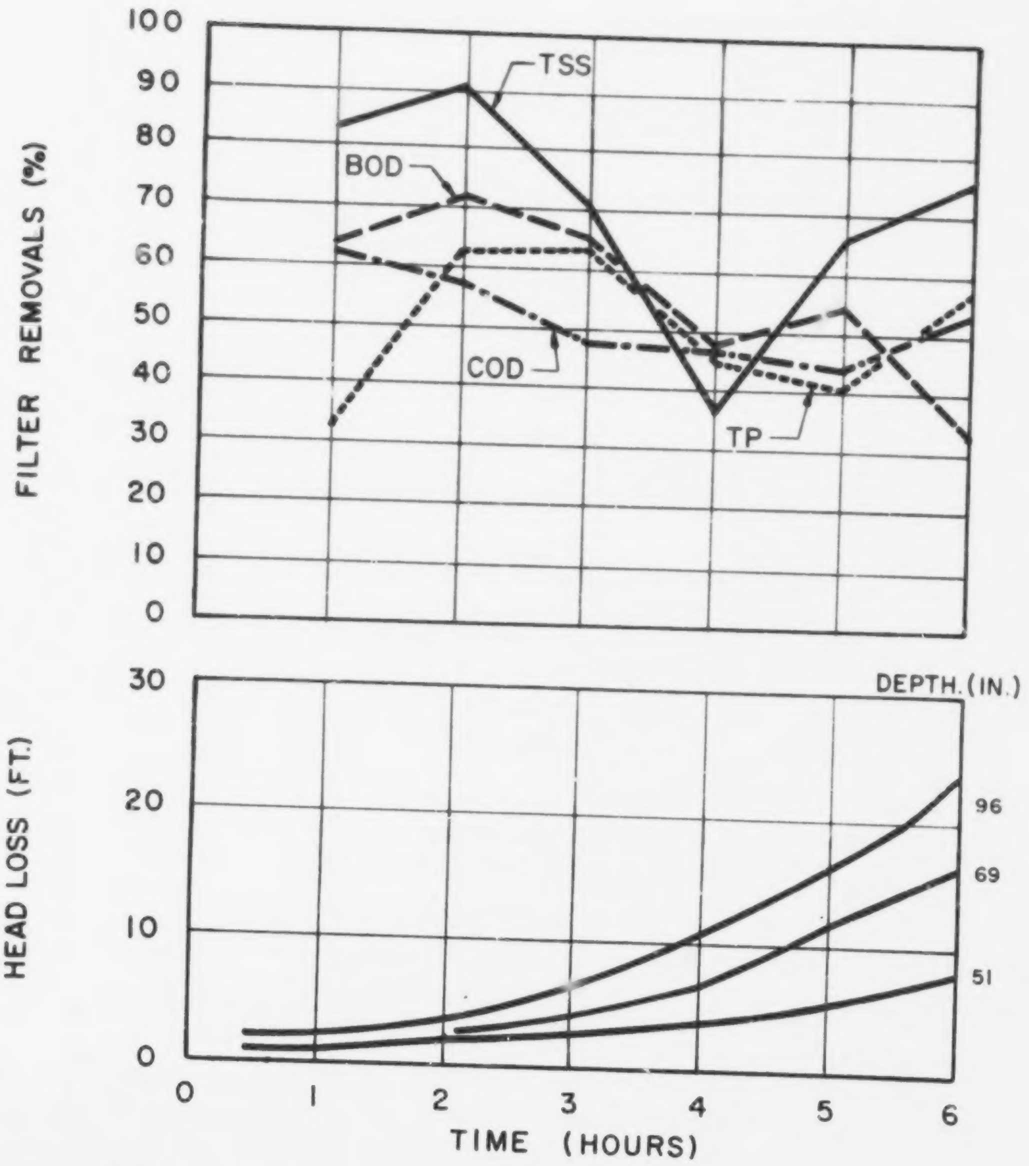
DATE 7/19/71 FLUX RATE 16 gpm/ft$^2$ COAG. ALUM. 30 mg/l

POLY. SWIFT X-400 1.0 mg/l

RUN No. 22SFIII

**COMBINED SEWER OVERFLOW FILTRATION TEST**

FIGURE C99



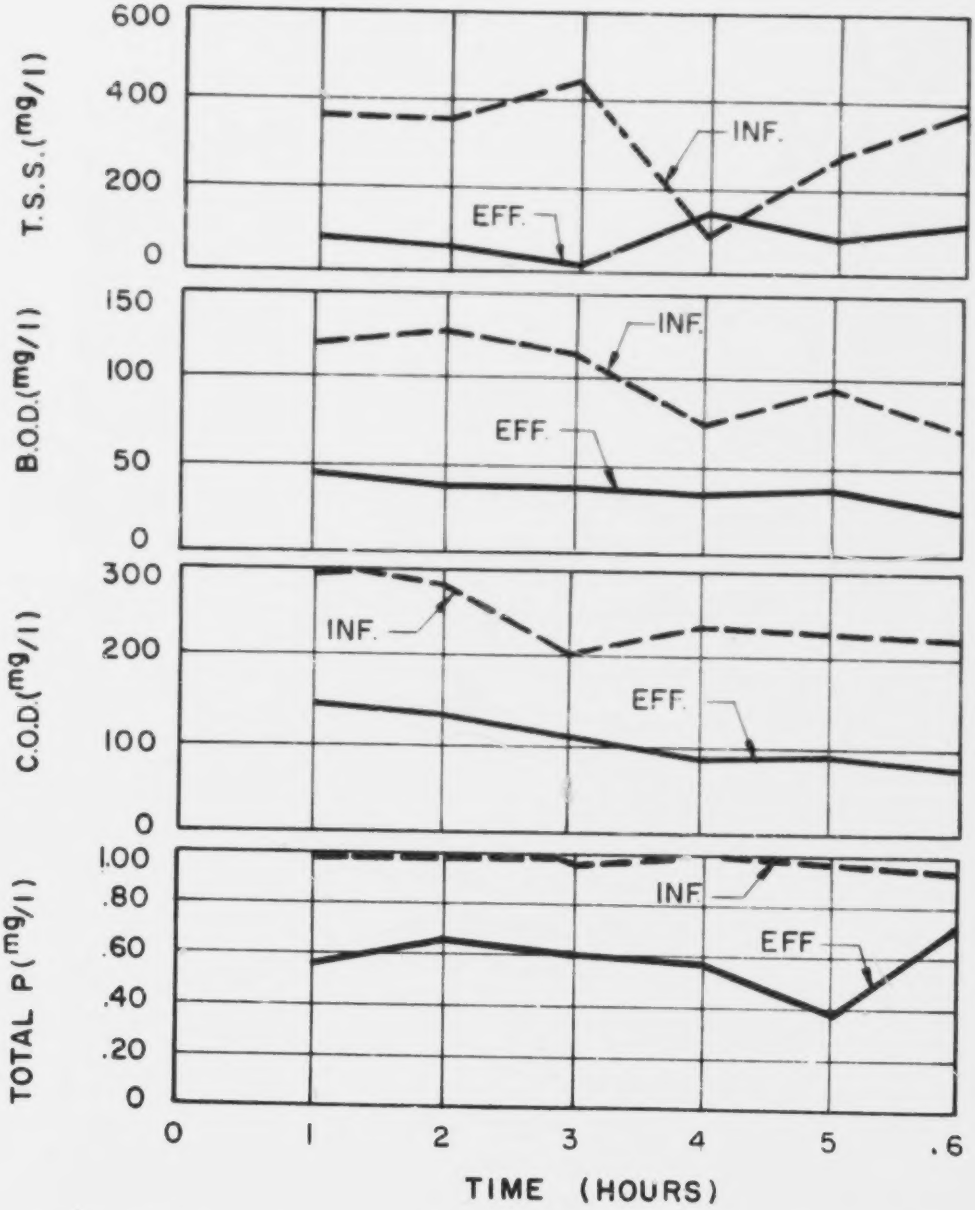
SCREEN 40 MESH. FILTER MEDIA 60 in. No. 3 ANTH./36 in. No. 612 SAND

DATE 7/19/71 FLUX RATE 16 gpm/ft$^2$ COAG. ALUM 30 mg/l

RUN No. 22SFIII POLY. SWIFTX-400 1.0 mg/l

## COMBINED SEWER OVERFLOW FILTRATION TEST

FIGURE C 100



SCREEN 40 MESH. FILTER MEDIA 60 in. No. 3 ANTH./36 in. No. 612 SAND

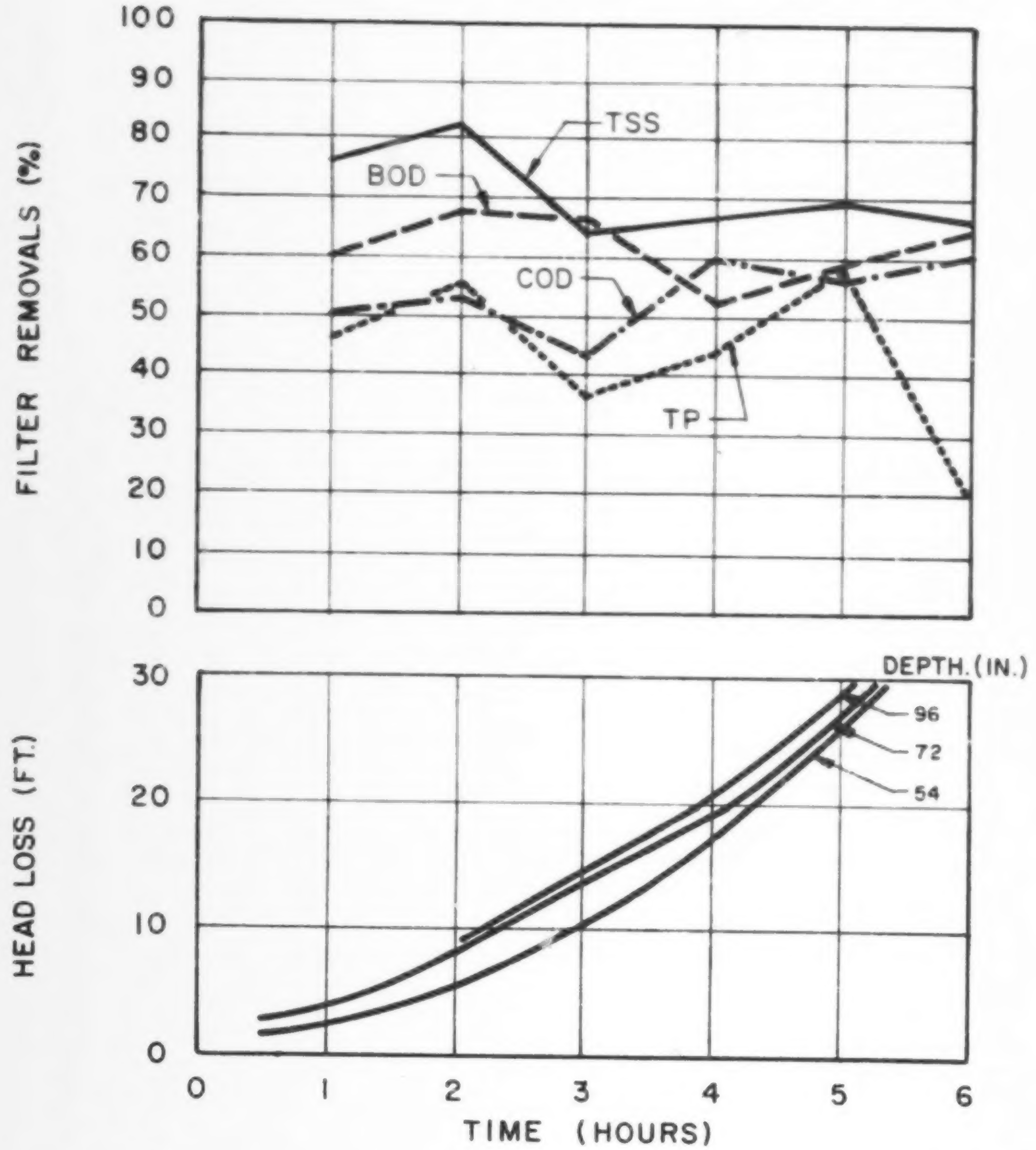
DATE 7/19/71 FLUX RATE 24 gpm/ft² COAG. ALUM. 30 mg/l

POLY. SWIFT X-400 1.0 mg/l

RUN No. 22SFIV

**COMBINED SEWER OVERFLOW FILTRATION TEST**

FIGURE C101



SCREEN 40 MESH. FILTER MEDIA. 60 in. No. 3 ANTH./36 in. No. 612 SAND

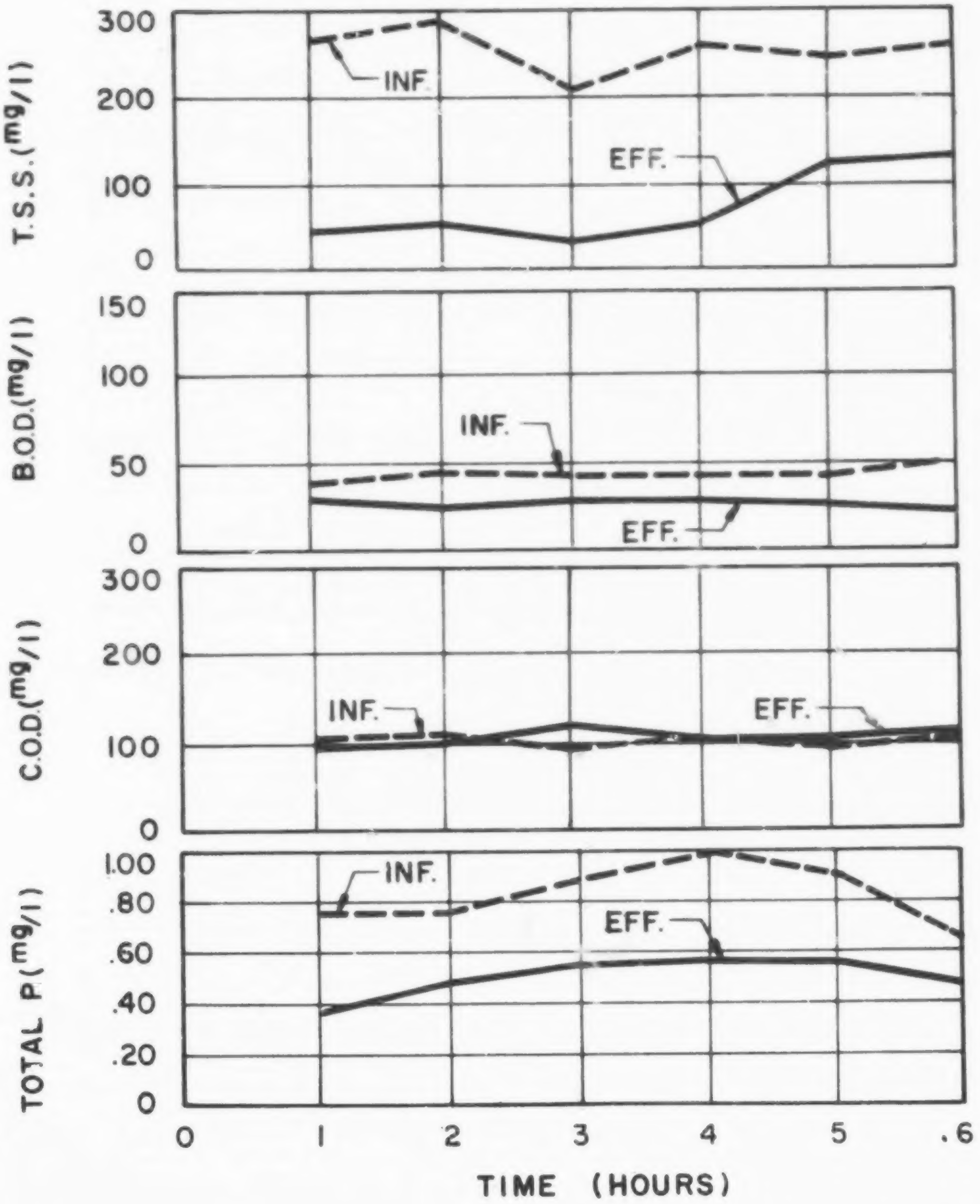
DATE 7/19/71 FLUX RATE 24 gpm/ft$^2$ COAG. ALUM 30 mg/l

POLY. SWIFT X-400 1.0 mg/l

RUN No. 22SFIV

COMBINED SEWER OVERFLOW FILTRATION TEST

FIGURE C102



SCREEN 40 MESH. FILTER MEDIA 60 in. No. 3 ANTH./36 in. No. 612 SAND

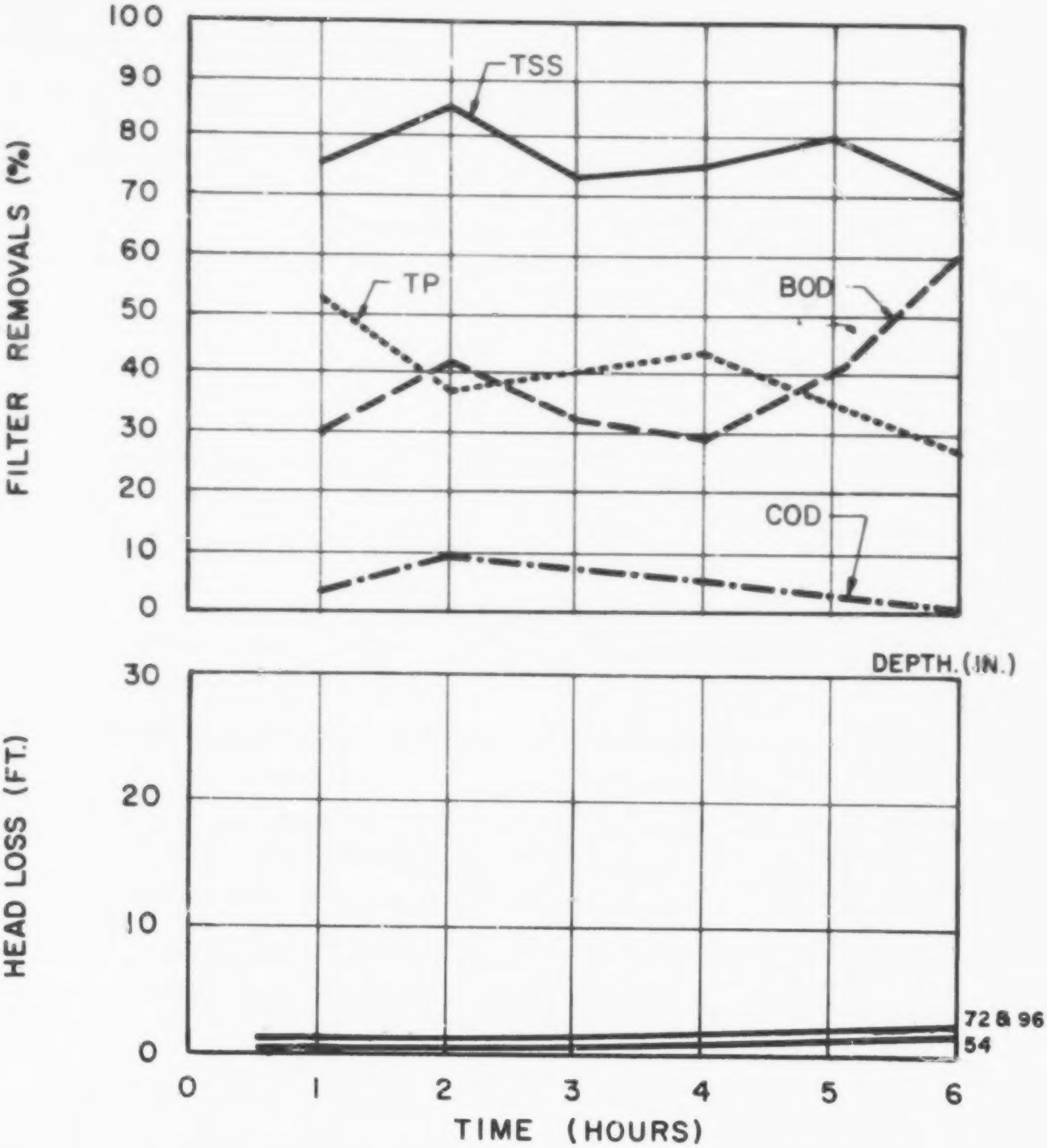
DATE 7/20/71 FLUX RATE 8 gpm/ft$^2$ COAG. ALUM 30 mg/l

POLY. ATLA.3A3 .5 mg/l

RUN No. 22ASFII

COMBINED SEWER OVERFLOW FILTRATION TEST

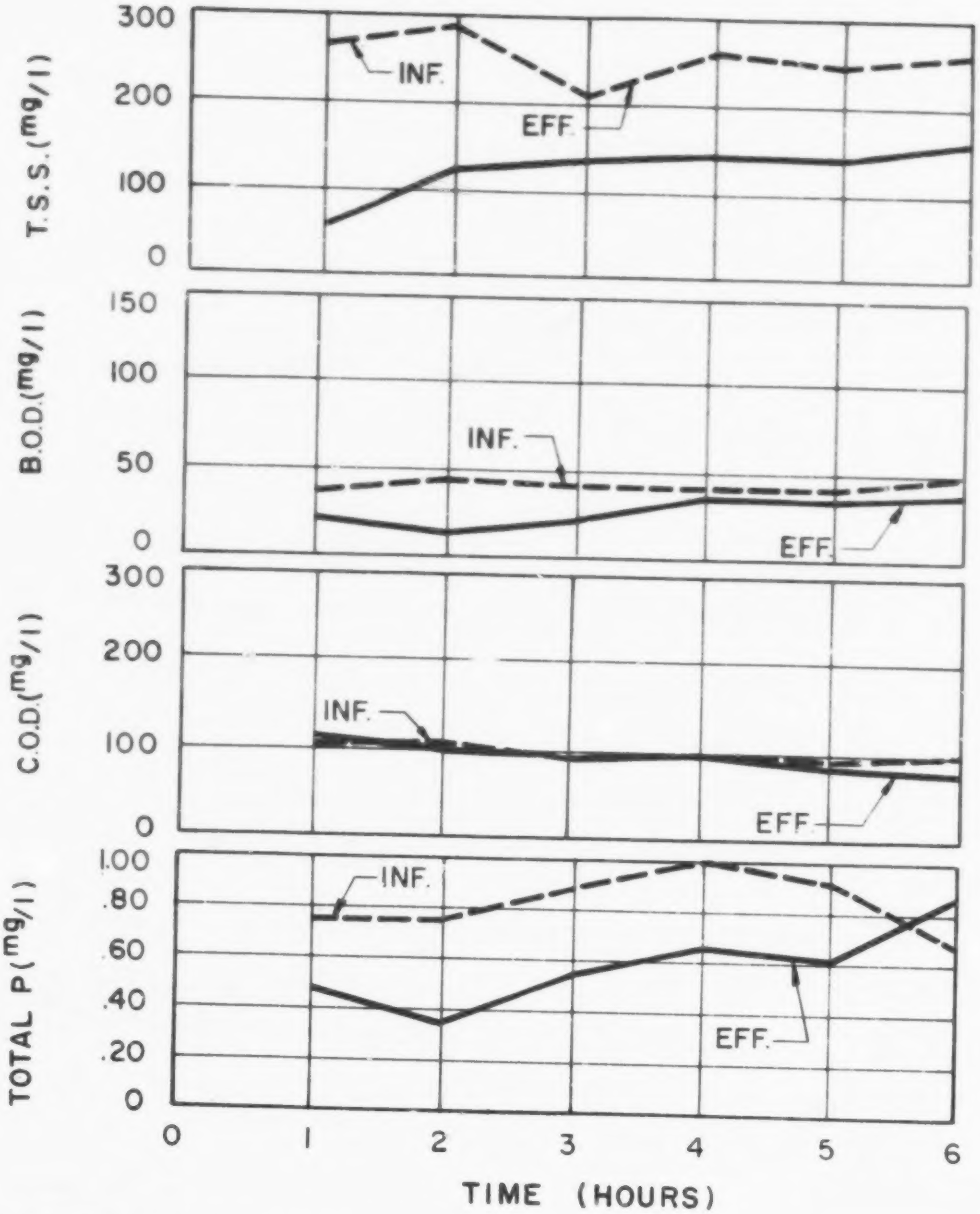
FIGURE C103



SCREEN 40 MESH. FILTER MEDIA. 60 in. No. 3 ANTH./ 36 in. No. 612 SAND
DATE 7/20/71 FLUX RATE 8 gpm/ft$^2$ COAG. ALUM 30 mg/l
POLY. ATLA.3A3 .5 mg/l
RUN No. 22ASFII

**COMBINED SEWER OVERFLOW FILTRATION TEST**

FIGURE C104



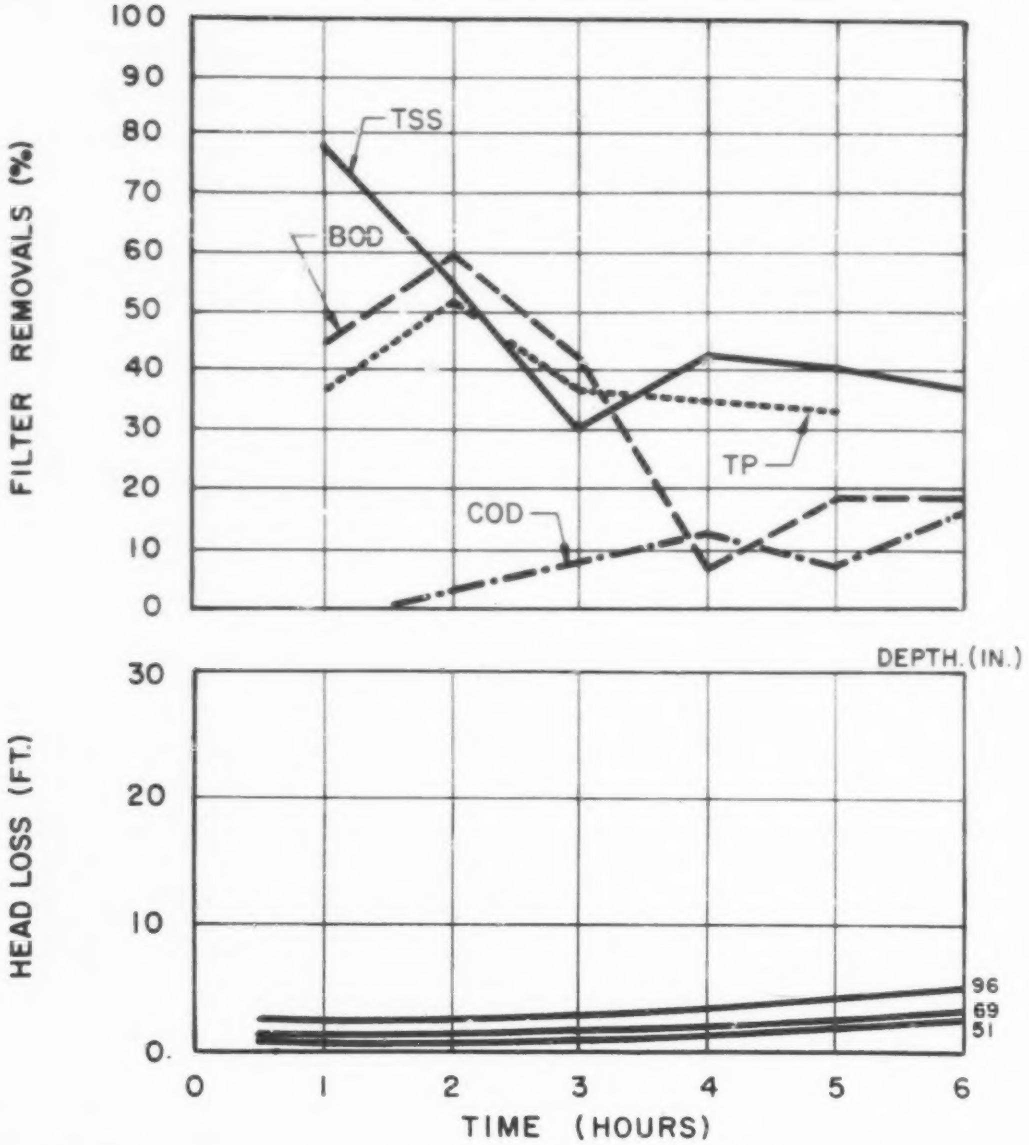
SCREEN 40 MESH. FILTER MEDIA 60 in. No. 3 ANTH./36 in. No. 612 SAND

DATE 7/20/71 FLUX RATE 16 gpm/$ft^2$ COAG. ALUM. 30 mg/l

RUN No. 22 ASF III POLY. ATLA. 3A3 .5 mg/l

**COMBINED SEWER OVERFLOW FILTRATION TEST**

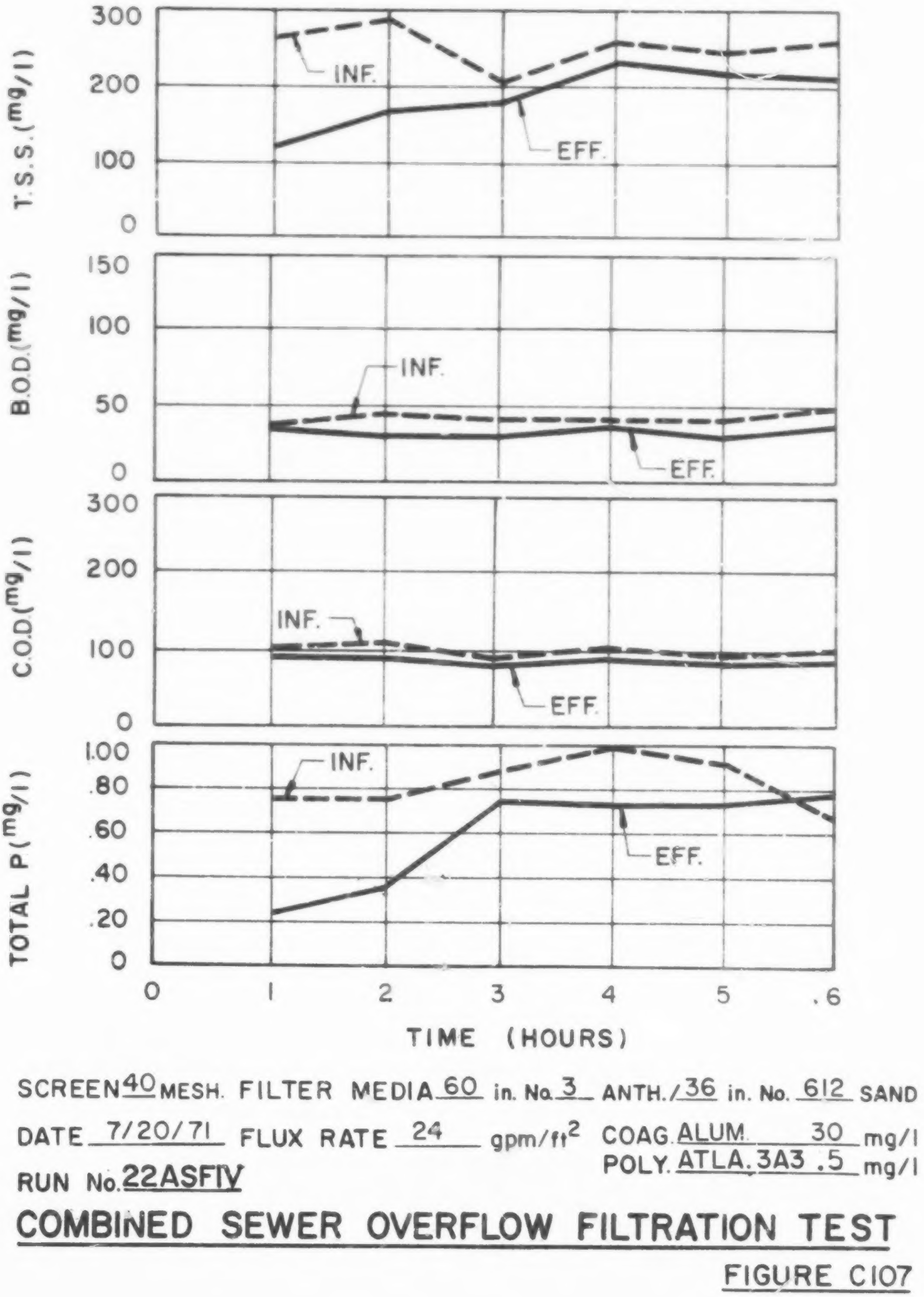
FIGURE C105



SCREEN 40 MESH. FILTER MEDIA. 60 in. No. 3 ANTH./ 36 in. No. 612 SAND
DATE 7/20/71 FLUX RATE 16 gpm/ft$^2$ COAG. ALUM 30 mg/l
POLY. ATLA 3A3 .5 mg/l
RUN No. 22ASFIII

COMBINED SEWER OVERFLOW FILTRATION TEST

FIGURE C106



SCREEN 40 MESH. FILTER MEDIA 60 in. No. 3 ANTH./36 in. No. 612 SAND

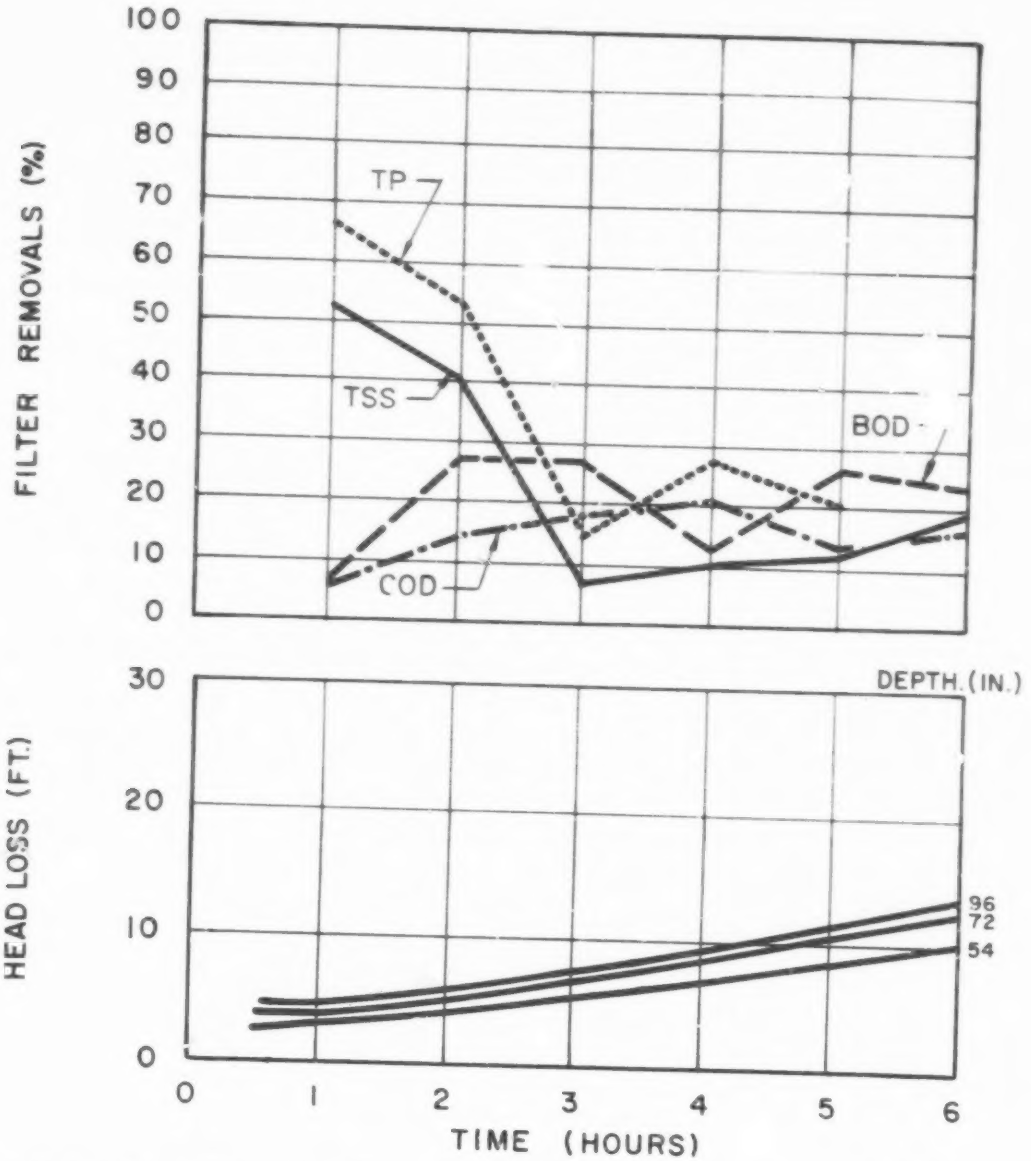
DATE 7/20/71 FLUX RATE 24 gpm/ft$^2$ COAG. ALUM. 30 mg/l

POLY. ATLA. 3A3 .5 mg/l

RUN No. 22ASFIV

**COMBINED SEWER OVERFLOW FILTRATION TEST**

FIGURE C107



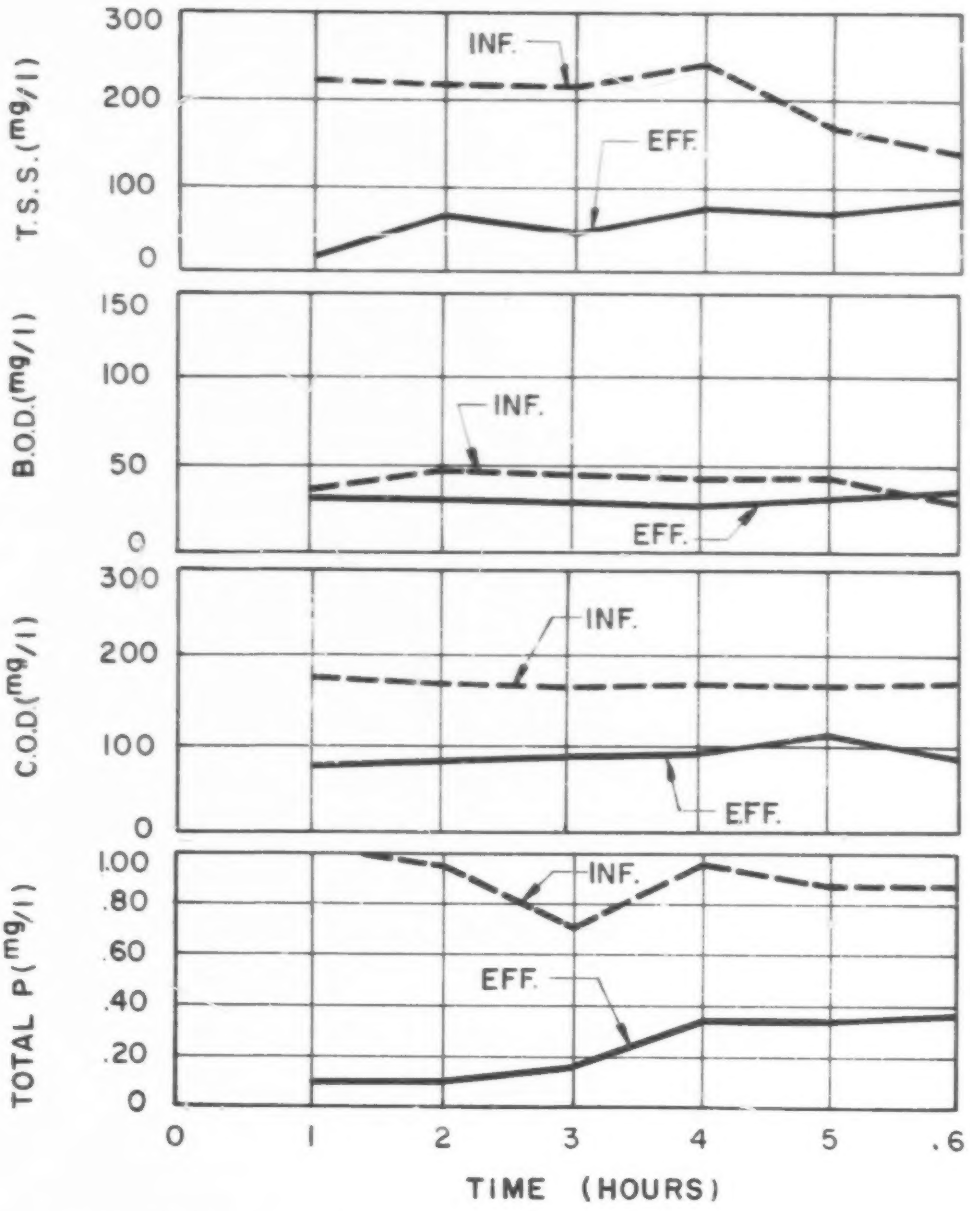
SCREEN 40 MESH. FILTER MEDIA 60 in. No. 3 ANTH./36 in. No. 612 SAND

DATE 7/20/71 FLUX RATE 24 gpm/ft$^2$ COAG. ALUM 30 mg/l

RUN No. 22ASFIV POLY. ATLA3A3 .5 mg/l

## COMBINED SEWER OVERFLOW FILTRATION TEST

FIGURE C108



SCREEN 40 MESH. FILTER MEDIA 60 in. No. 3 ANTH. / 36 in. No. 612 SAND

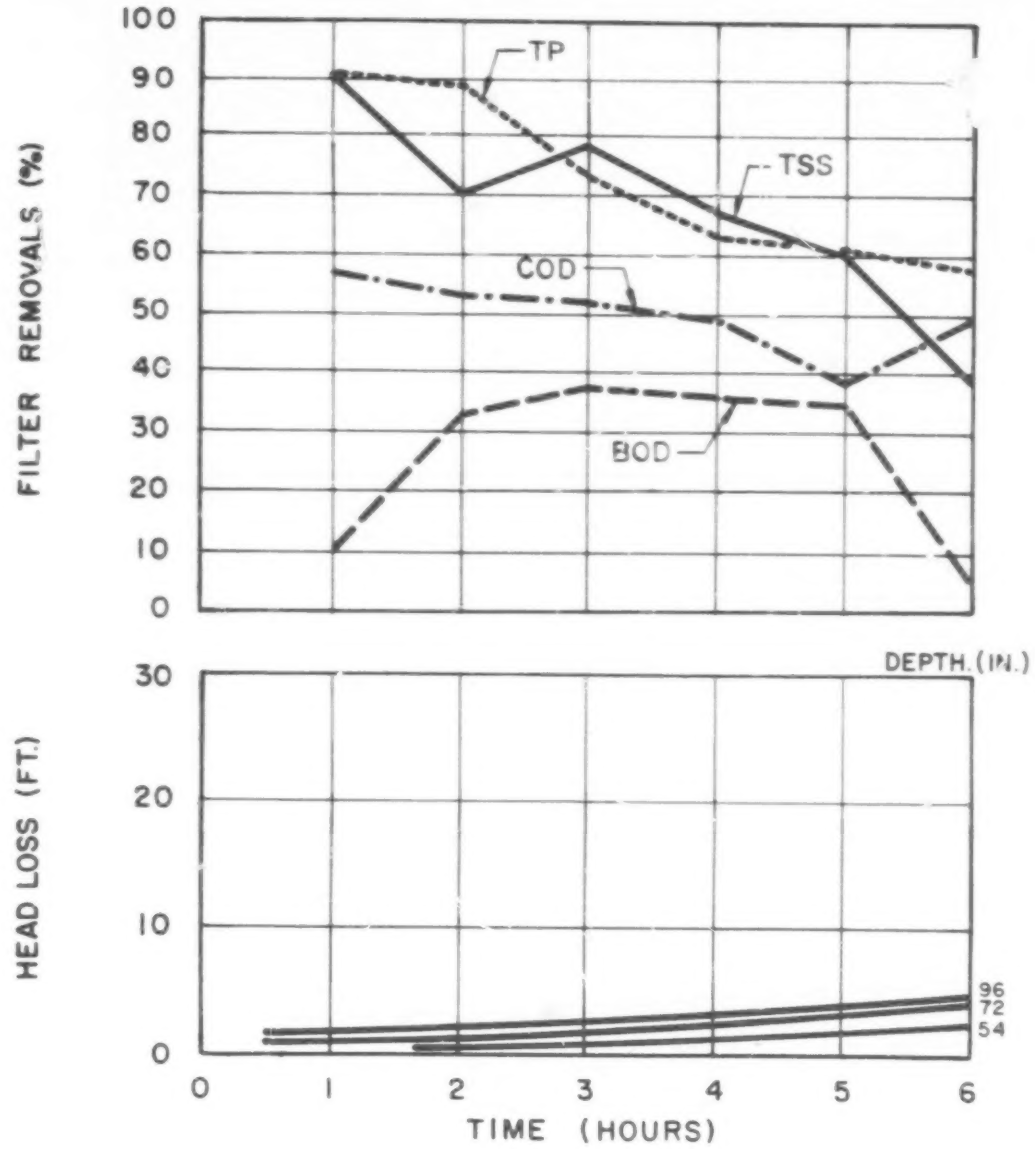
DATE 7/21/71 FLUX RATE 8 gpm/ft$^2$ COAG. ALUM. 30 mg/l

POLY. PURIFL. A-23 1.0 mg/l

RUN No. 22BSFII

COMBINED SEWER OVERFLOW FILTRATION TEST

FIGURE C109



SCREEN 40 MESH. FILTER MEDIA 60 in. No. 3 ANTH./ 36 in. No. 612 SAND

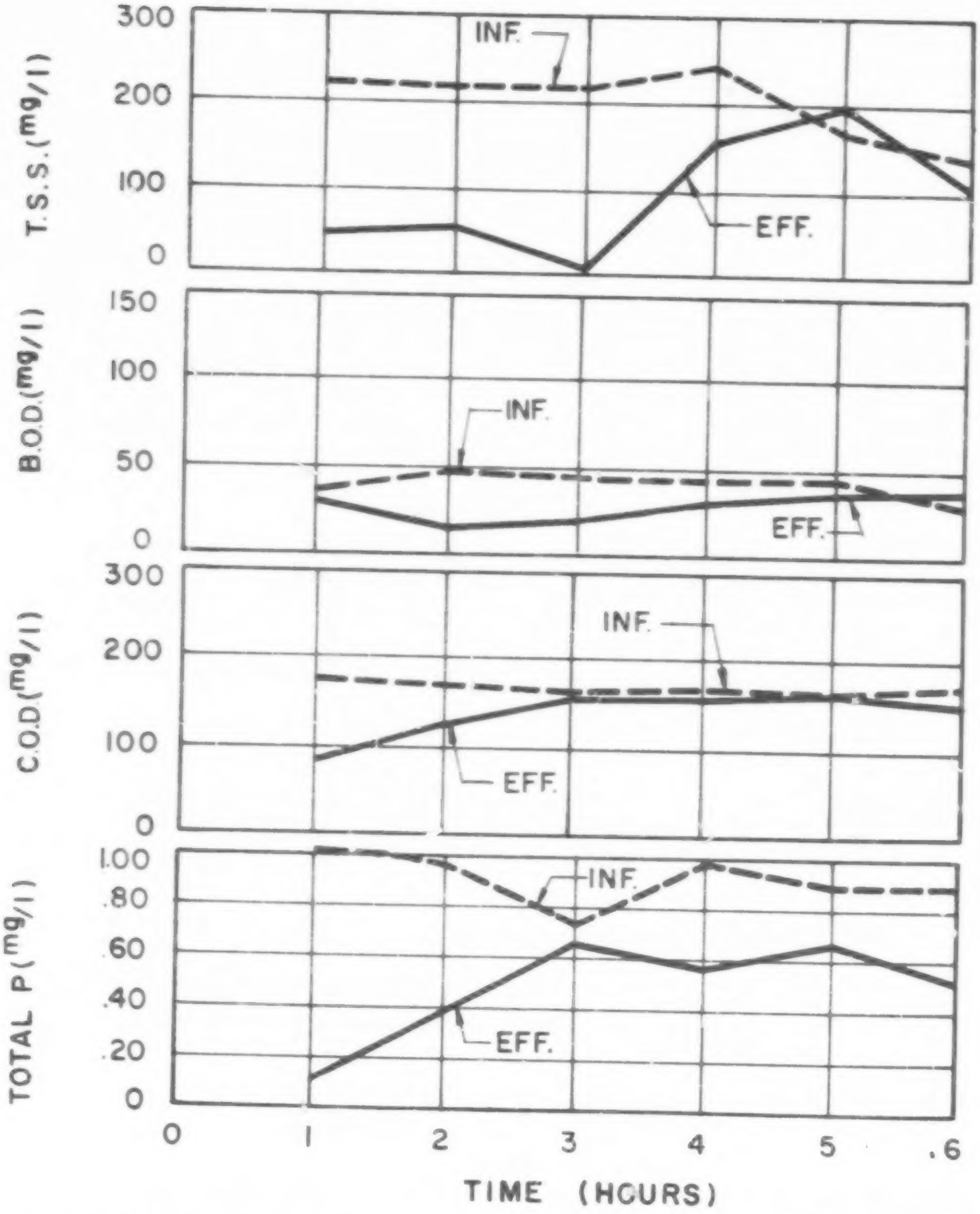
DATE 7/21/71 FLUX RATE 8 gpm/ft² COAG. ALUM 30 mg/l

POLY. PURIFL A-23 1.0 mg/l

RUN No. 22BSFII

COMBINED SEWER OVERFLOW FILTRATION TEST

FIGURE C110



SCREEN 40 MESH. FILTER MEDIA 60 in. No. 3 ANTH./36 in. No. 612 SAND

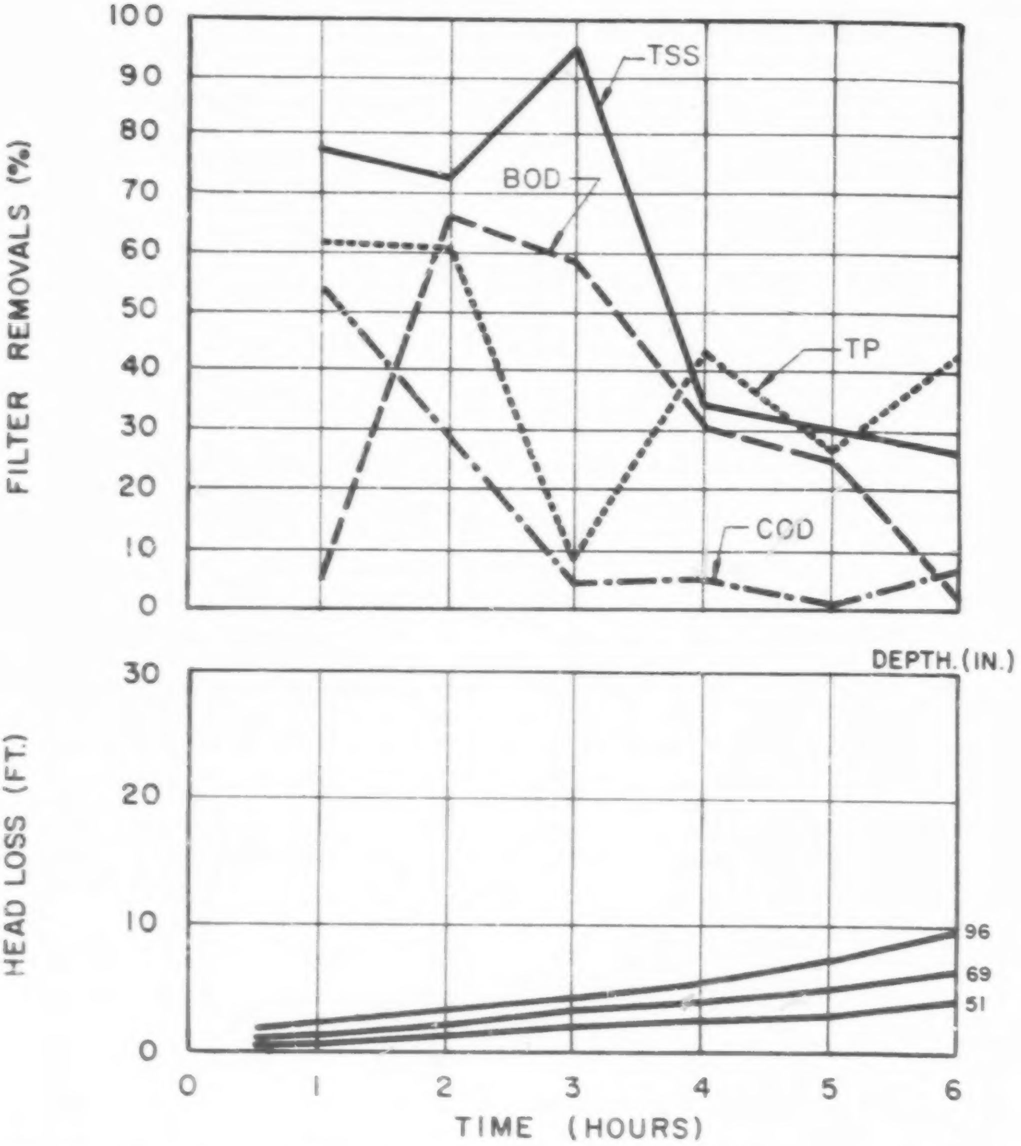
DATE 7/21/71 FLUX RATE 16 gpm/ft$^2$ COAG. ALUM. 30 mg/l

POLY. PURIFL. A-23 1.0 mg/l

RUN No. 22BSFIII

## COMBINED SEWER OVERFLOW FILTRATION TEST

FIGURE CIII



SCREEN 40 MESH. FILTER MEDIA 60 in. No. 3 ANTH./36 in. No. 612 SAND

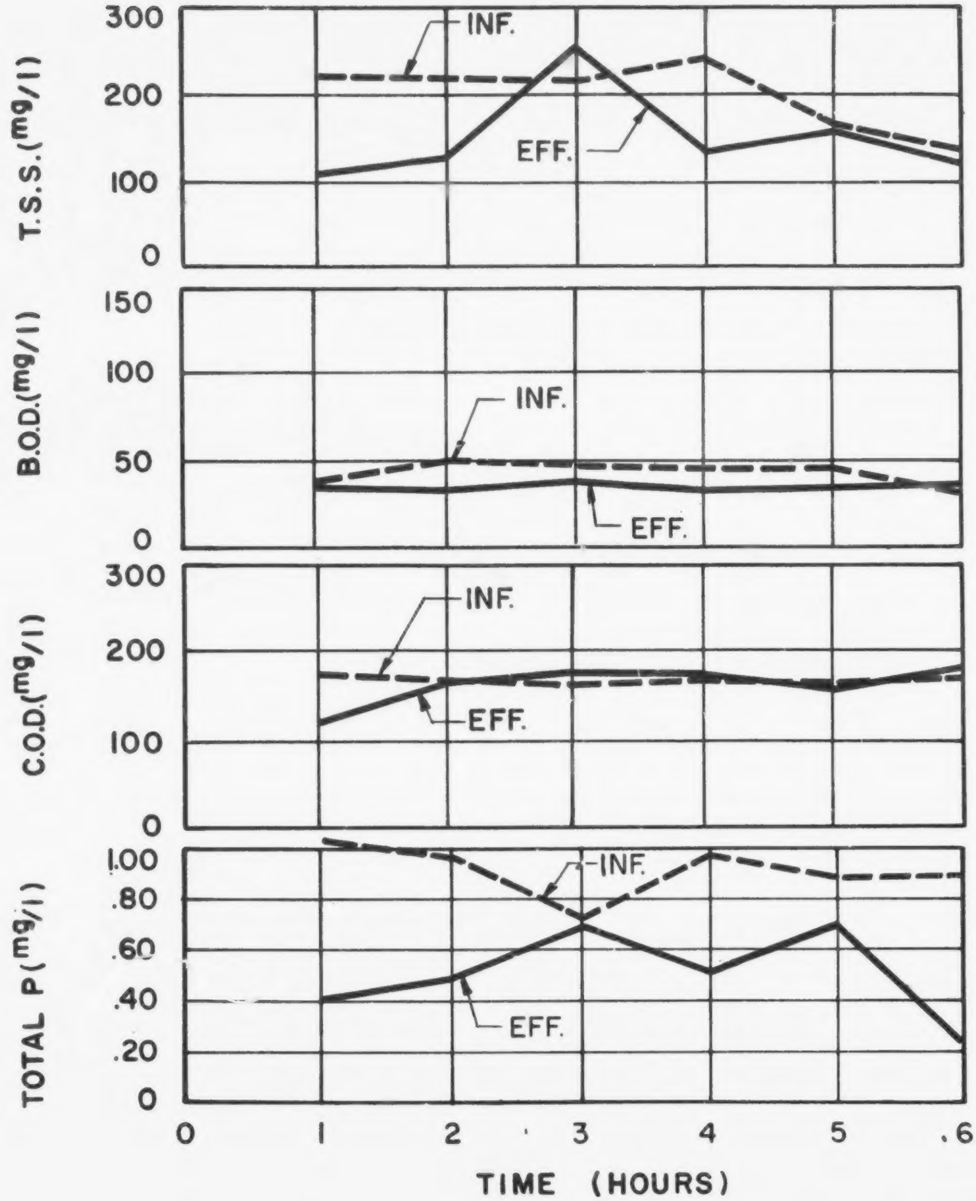
DATE 7/21/71 FLUX RATE 16 gpm/ft$^2$ COAG. ALUM 30 mg/l

POLY. PURIFL. A-23 1.0 mg/l

RUN No. 22BSFIII

## COMBINED SEWER OVERFLOW FILTRATION TEST

FIGURE C112



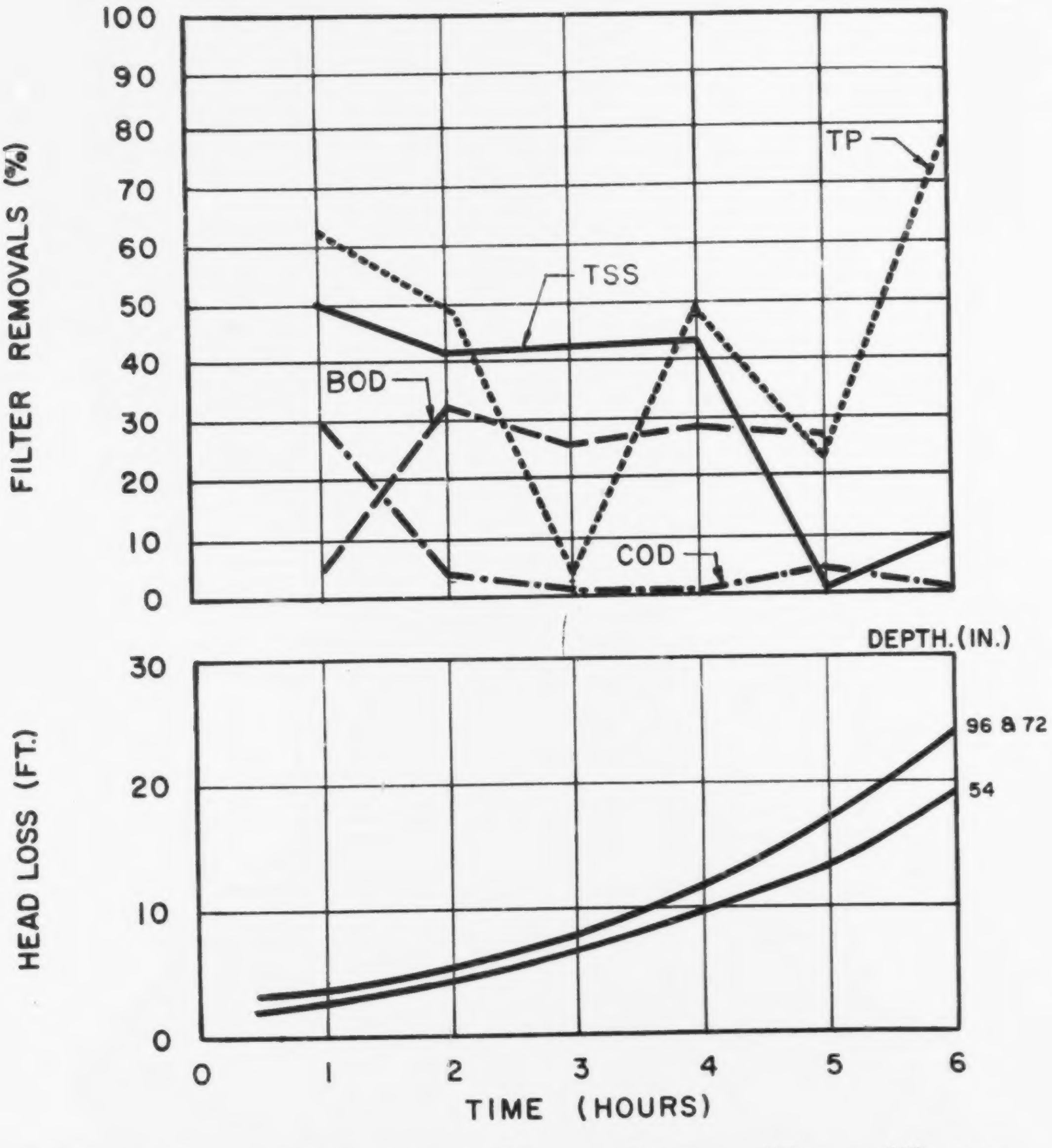
SCREEN 40 MESH. FILTER MEDIA 60 in. No. 3 ANTH. / 36 in. No. 612 SAND

DATE 7/21/71 FLUX RATE 24 gpm/ft$^2$ COAG. ALUM. 30 mg/l
POLY. PURIFL. A-23 1.0 mg/l

RUN No. 22BSFIV

**COMBINED SEWER OVERFLOW FILTRATION TEST**

FIGURE C113



SCREEN 40 MESH. FILTER MEDIA. 60 in. No. 3 ANTH./36 in. No. 612 SAND

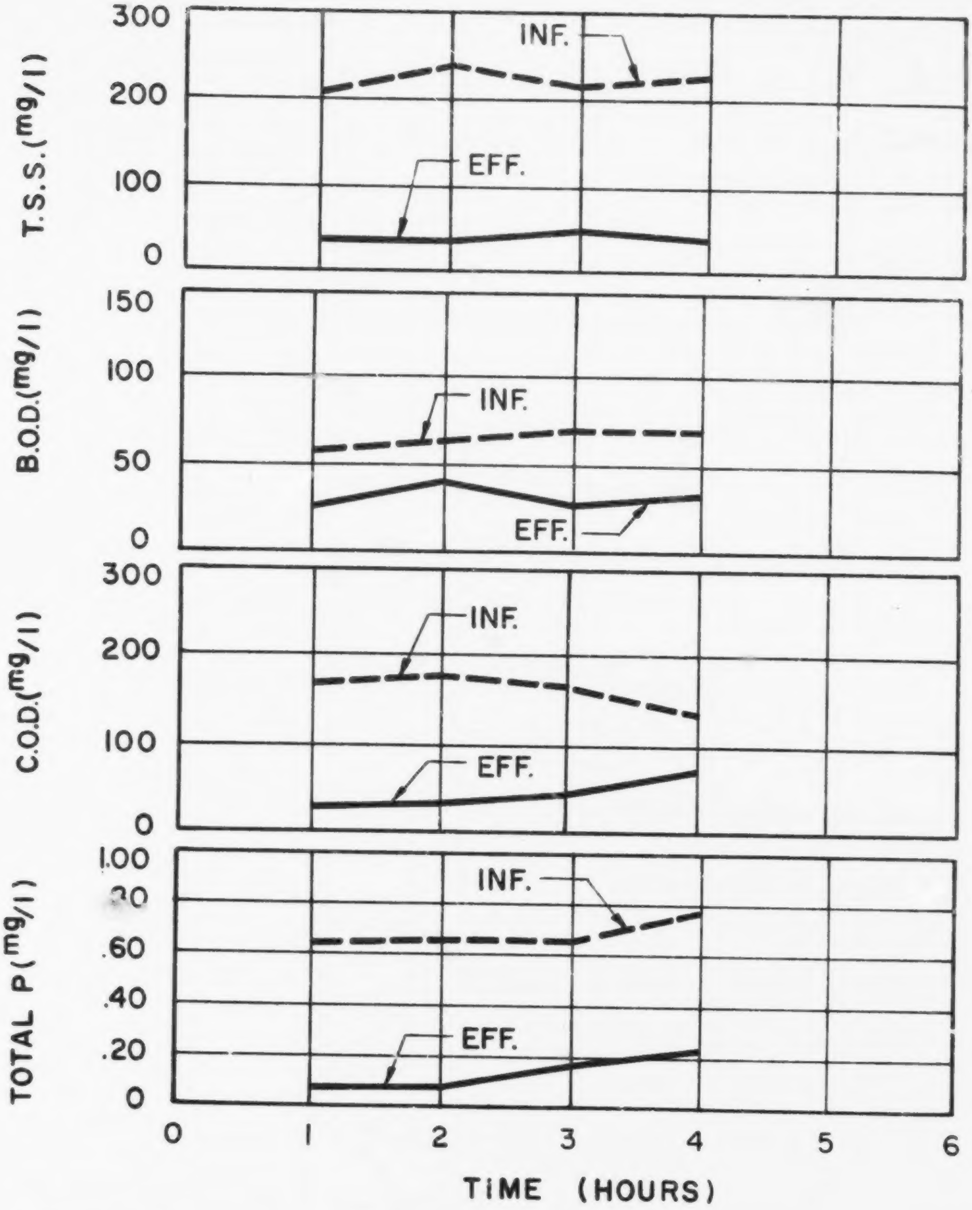
DATE 7/21/71 FLUX RATE 24 gpm/ft$^2$ COAG. ALUM 30 mg/l

POLY. PURIFL A-23 1.0 mg/l

RUN No. 22BSFIV

**COMBINED SEWER OVERFLOW FILTRATION TEST**

FIGURE C114



SCREEN 40 MESH. FILTER MEDIA 60 in. No. 3 ANTH./36 in. No. 612 SAND

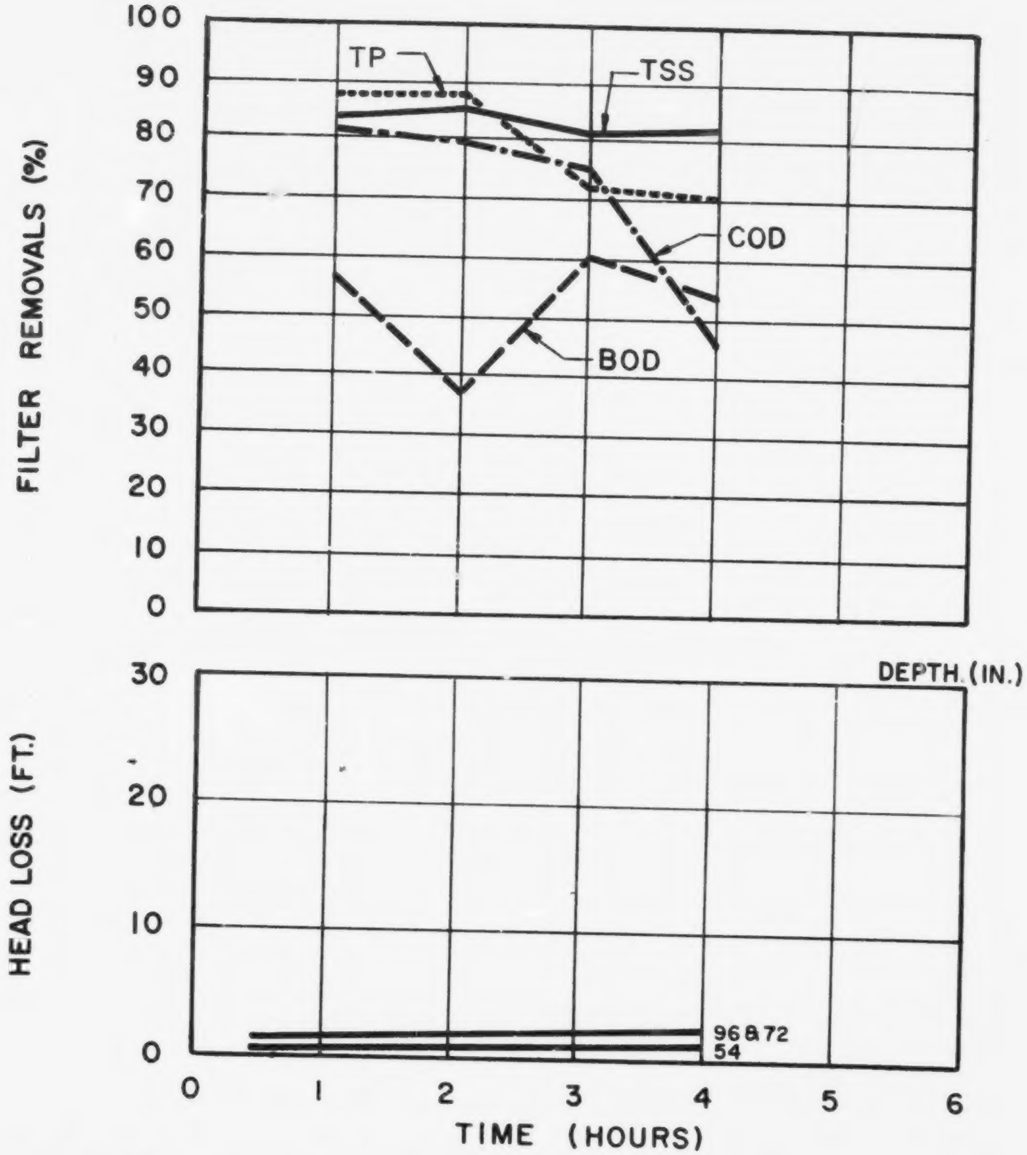
DATE 7/22/71 FLUX RATE 8 gpm/ft$^2$ COAG. ALUM. 30 mg/l

POLY. PURIFL. C-31 1.0 mg/l

RUN No. 22CSFII

COMBINED SEWER OVERFLOW FILTRATION TEST

FIGURE C115



SCREEN 40 MESH. FILTER MEDIA 60 in. No. 3 ANTH./36 in. No. 612 SAND

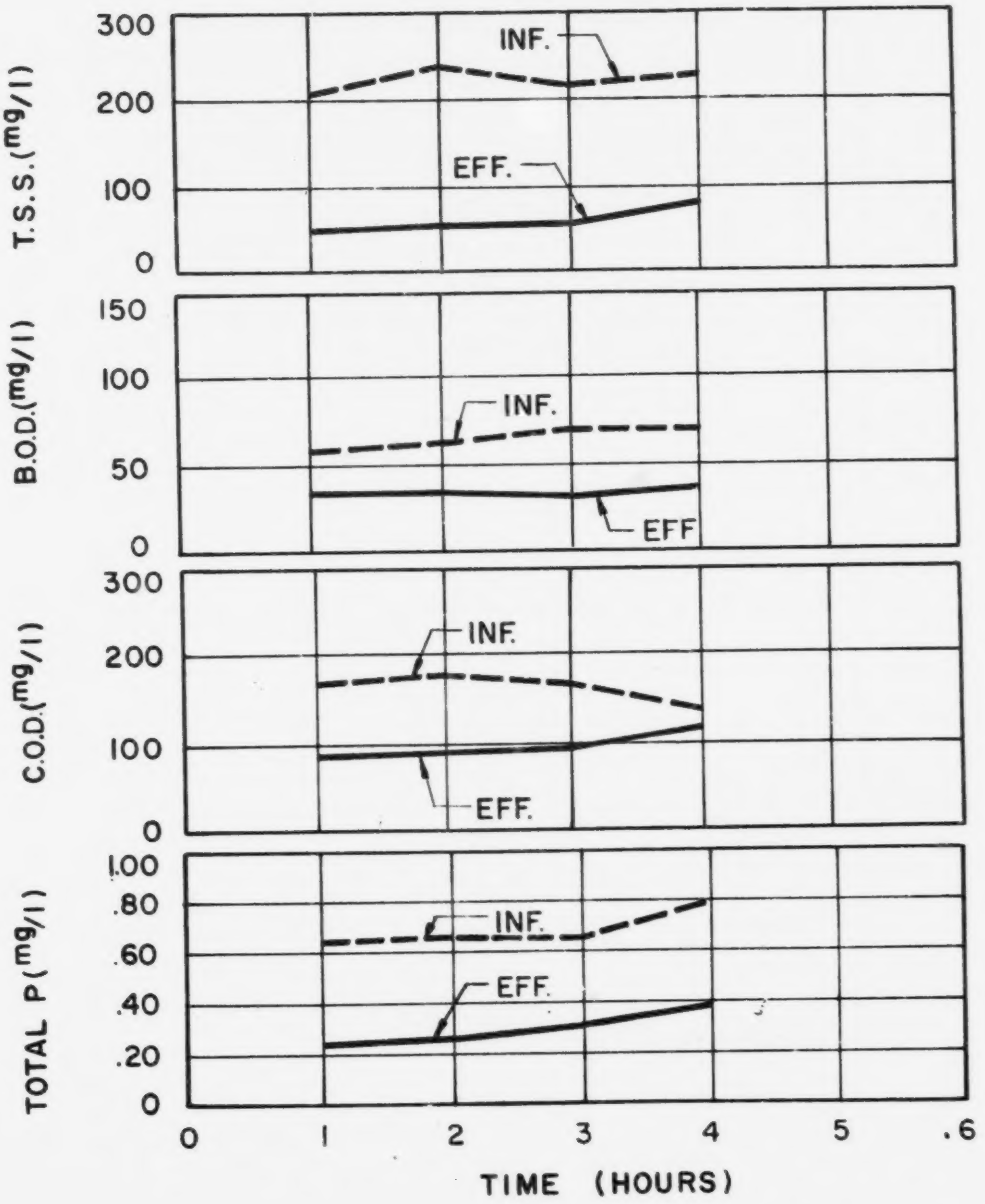
DATE 7/22/71 FLUX RATE 8 gpm/ft² COAG. ALUM 30 mg/l

POLY PURIFL. C-31 1.0 mg/l

RUN No. 22CSFII

COMBINED SEWER OVERFLOW FILTRATION TEST

FIGURE C116



SCREEN 40 MESH. FILTER MEDIA 60 in. No. 3 ANTH. / 36 in. No. 612 SAND

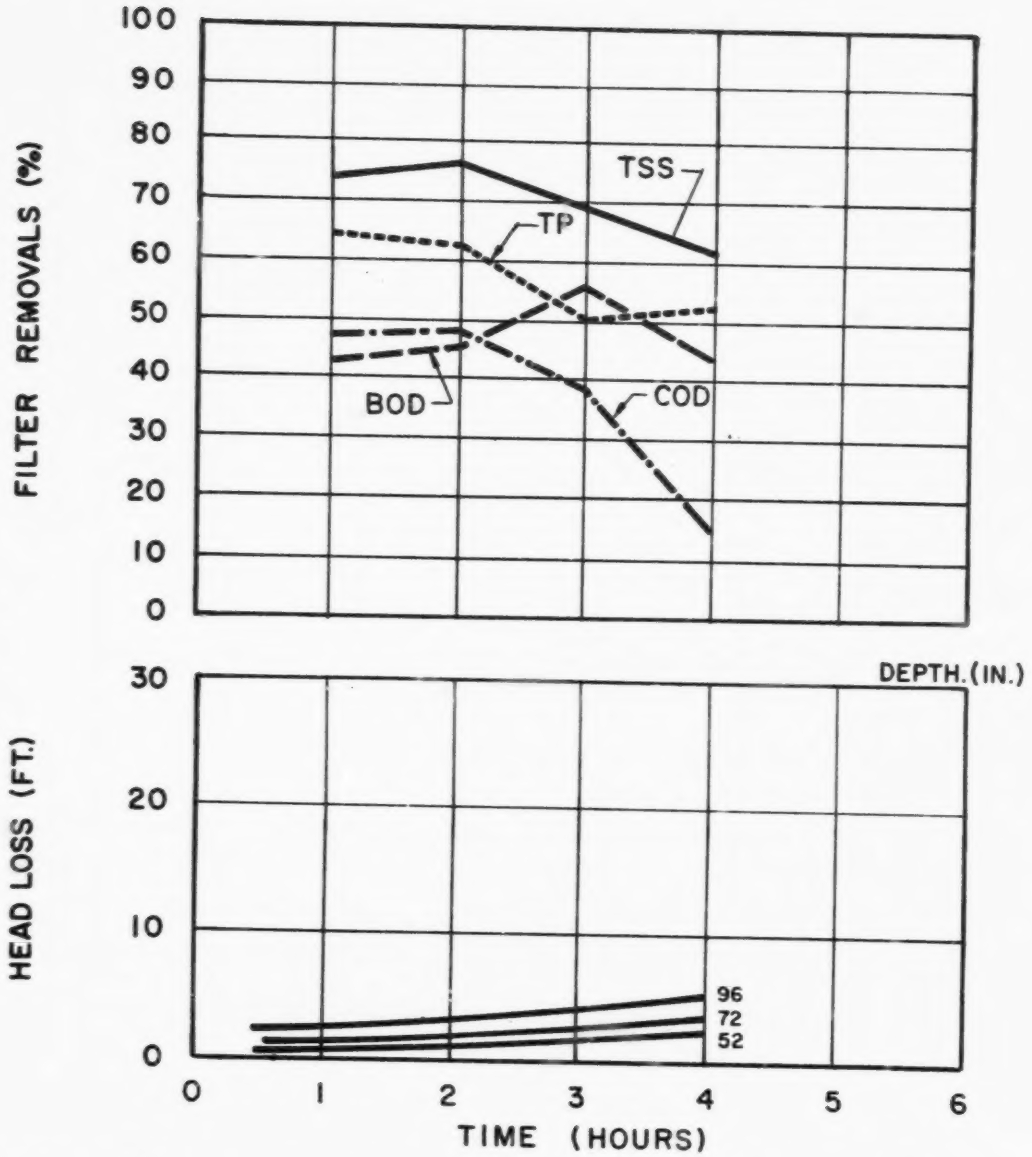
DATE 7/22/71 FLUX RATE 16 gpm/ft$^2$ COAG. ALUM 30 mg/l

POLY. PURIFL. C-31 1.0 mg/l

RUN No. 22CSFIII

**COMBINED SEWER OVERFLOW FILTRATION TEST**

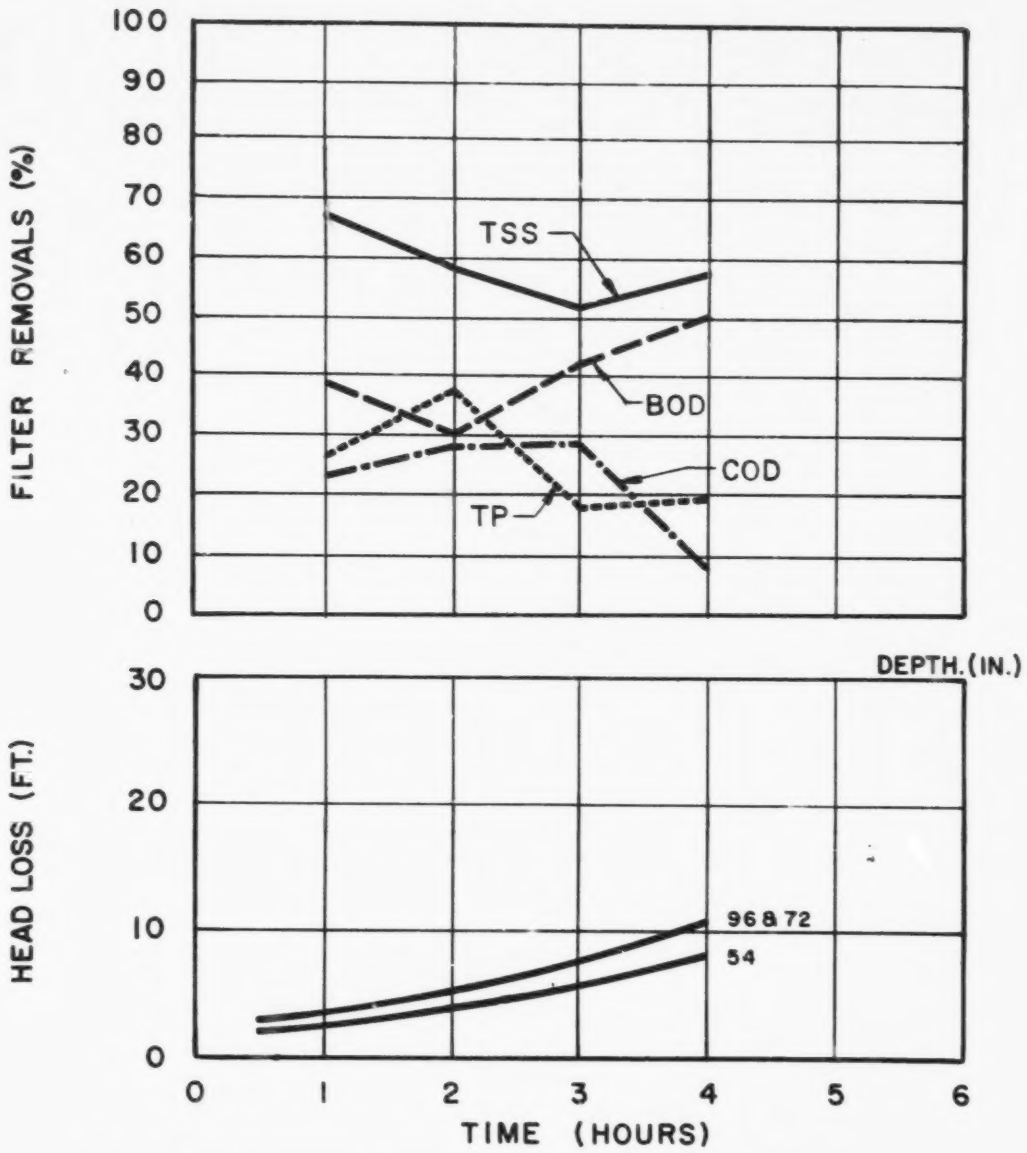
FIGURE C117



SCREEN 40 MESH. FILTER MEDIA. 60 in. No. 3 ANTH./36 in. No. 612 SAND
DATE 7/22/71 FLUX RATE 16 gpm/ft² COAG. ALUM 30 mg/l
POLY. PURIFL. C-31 1.0 mg/l
RUN No. 22CSFIII

COMBINED SEWER OVERFLOW FILTRATION TEST

FIGURE C118



SCREEN 40 MESH. FILTER MEDIA. 60 in. No. 3 ANTH./36 in. No. 612 SAND

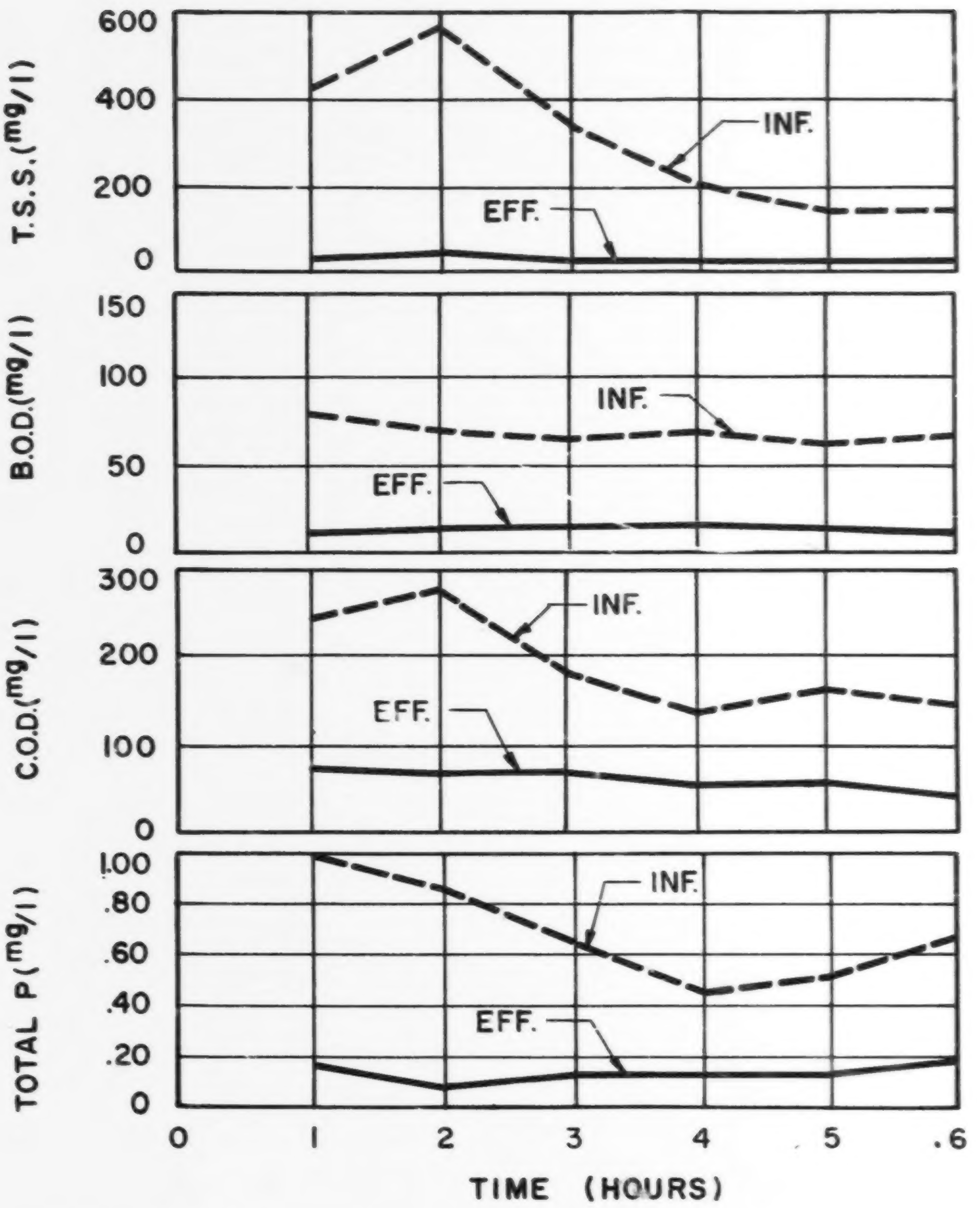
DATE 7/22/71 FLUX RATE 24 gpm/ft$^2$ COAG. ALUM. 30 mg/l

POLY. PURIFL. C-31 1.0 mg/l

RUN No. 22CSF!V

COMBINED SEWER OVERFLOW FILTRATION TEST

FIGURE C120



SCREEN 40 MESH. FILTER MEDIA 60 in. No. 3 ANTH./36 in. No. 612 SAND

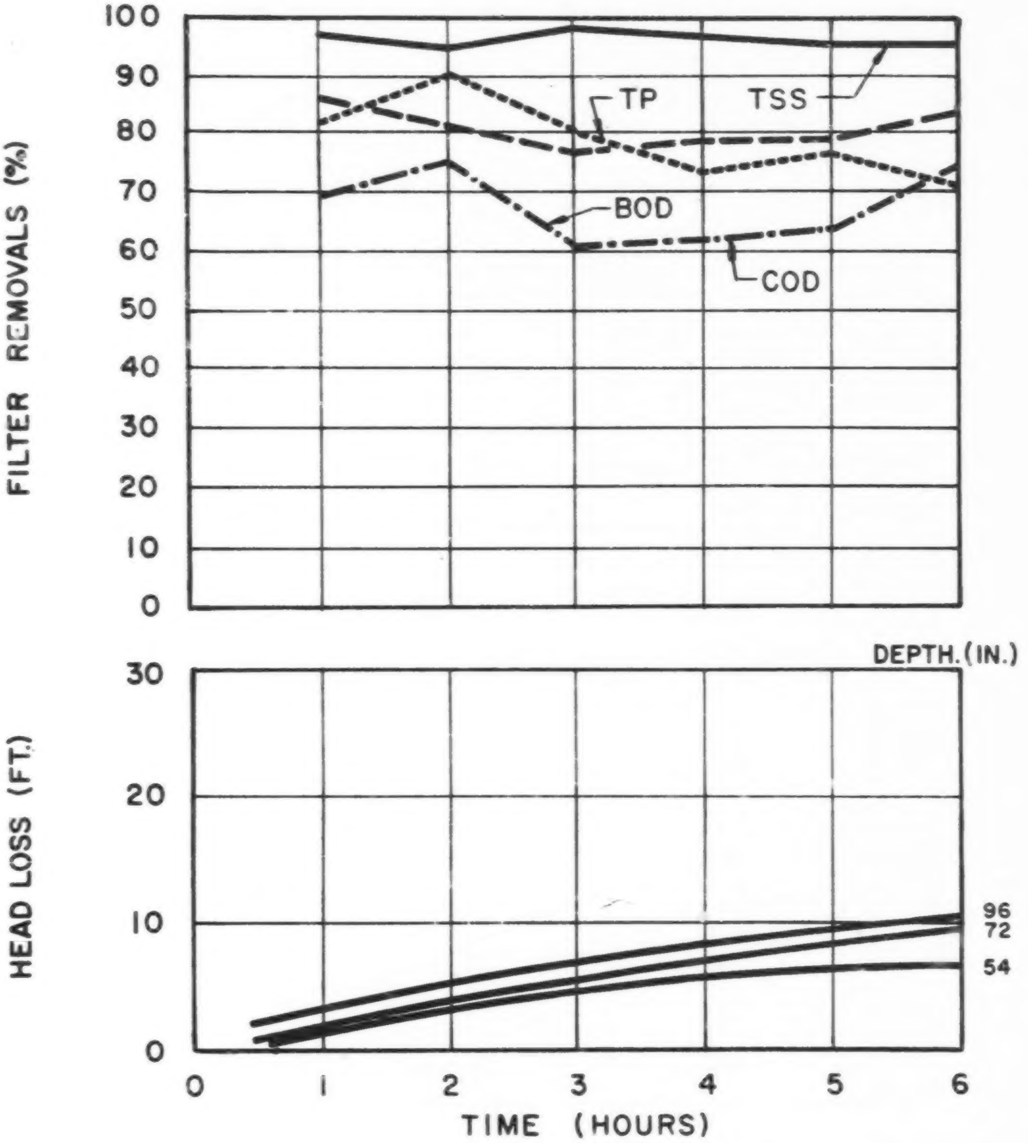
DATE 7/24/71 FLUX RATE 8 gpm/ft$^2$ COAG. 0 mg/l

POLY. ATLA. 4A4 1.0 mg/l

RUN No. 23SFII

## COMBINED SEWER OVERFLOW FILTRATION TEST

FIGURE C 121



SCREEN 40 MESH. FILTER MEDIA. 60 in. No. 3 ANTH./ 36 in. No. 612 SAND

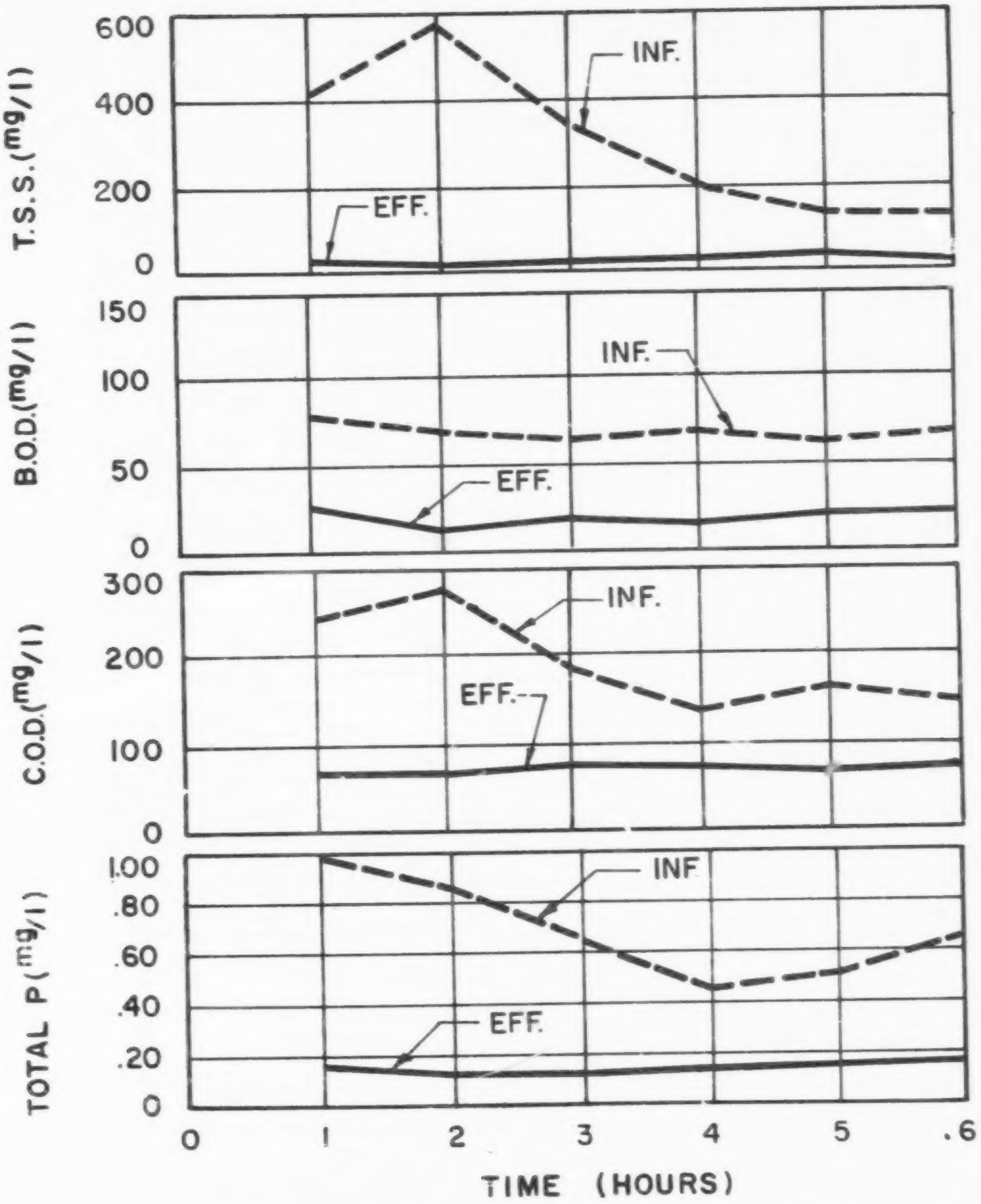
DATE 7/24/71 FLUX RATE 8 gpm/ft² COAG. 0 mg/l

POLY. ATLA. 4A4 1.0 mg/l

RUN No. 23SFII

COMBINED SEWER OVERFLOW FILTRATION TEST

FIGURE C122



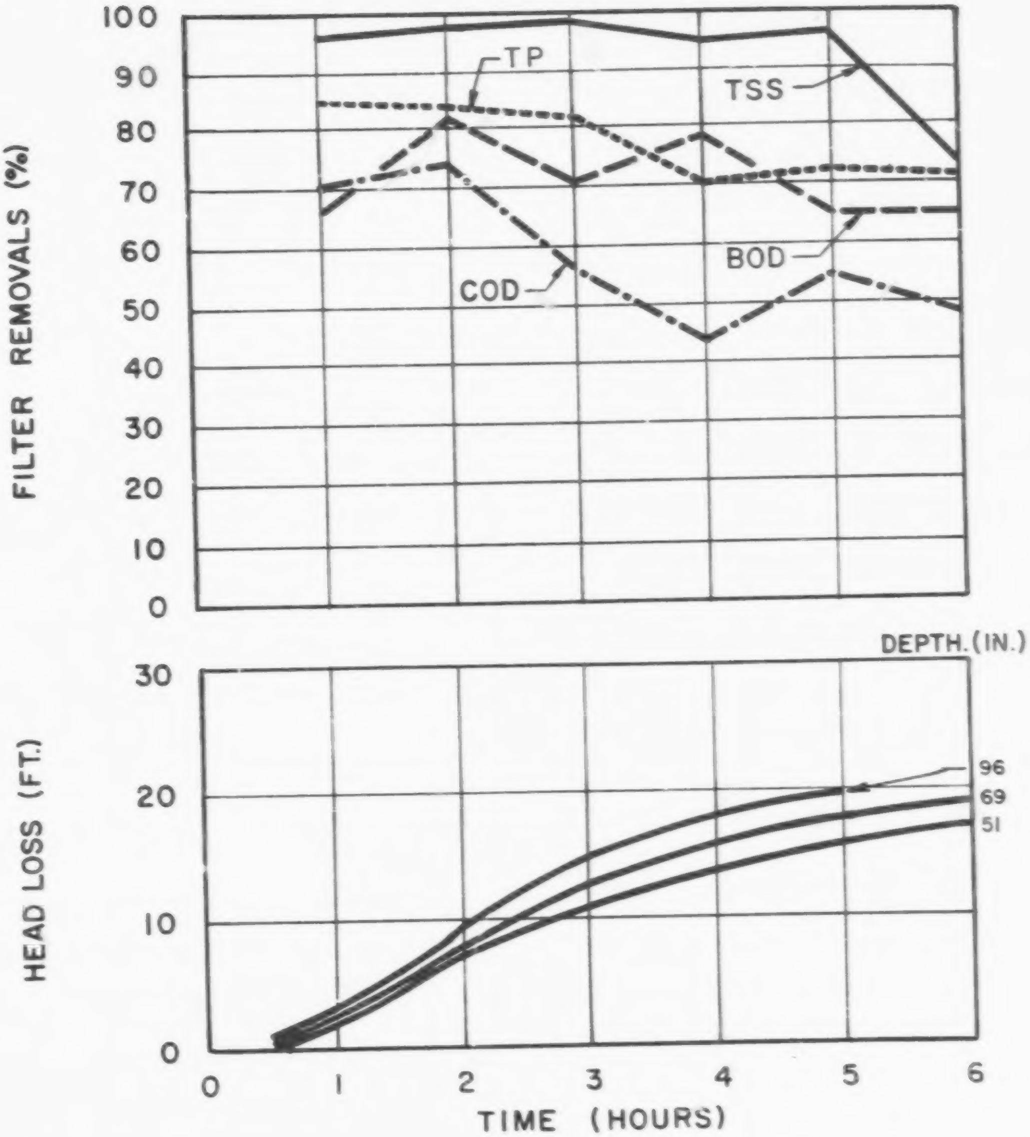
SCREEN 40 MESH. FILTER MEDIA 60 in. No. 3 ANTH./36 in. No. 612 SAND

DATE 7/24/71 FLUX RATE 16 gpm/ft$^2$ COAG. 0 mg/l
POLY. ATLA. 4A4 1.0 mg/l

RUN No. 23SFIII

## COMBINED SEWER OVERFLOW FILTRATION TEST

FIGURE C123



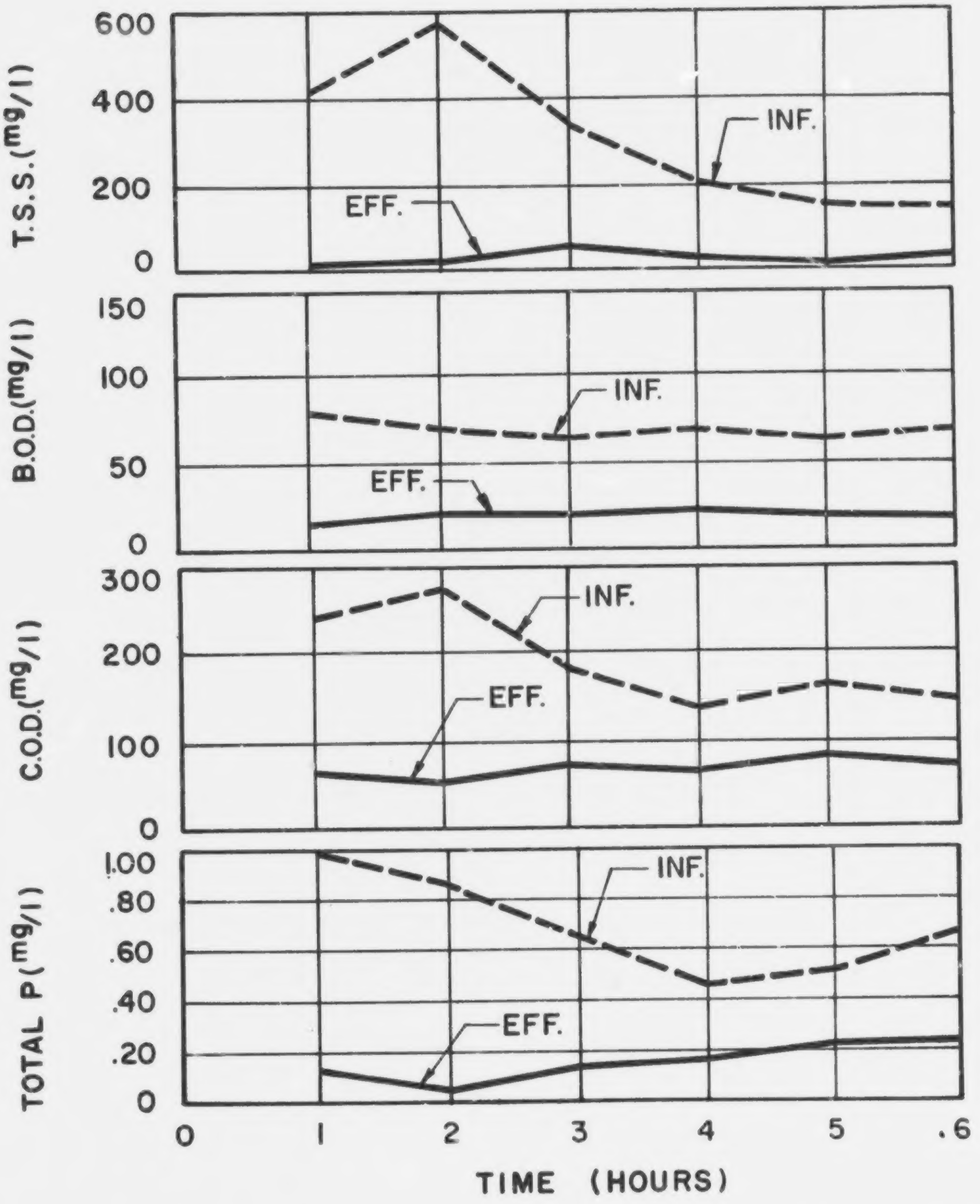
SCREEN 40 MESH. FILTER MEDIA 60 in. No. 3 ANTH./36 in. No. 612 SAND

DATE 7/24/71 FLUX RATE 16 gpm/ft$^2$ COAG. 0 mg/l
POLY ATLA. 4A4 1.0 mg/l

RUN No. 23SFIII

COMBINED SEWER OVERFLOW FILTRATION TEST

FIGURE C124



SCREEN 40 MESH. FILTER MEDIA 60 in. No. 3 ANTH./36 in. No. 612 SAND

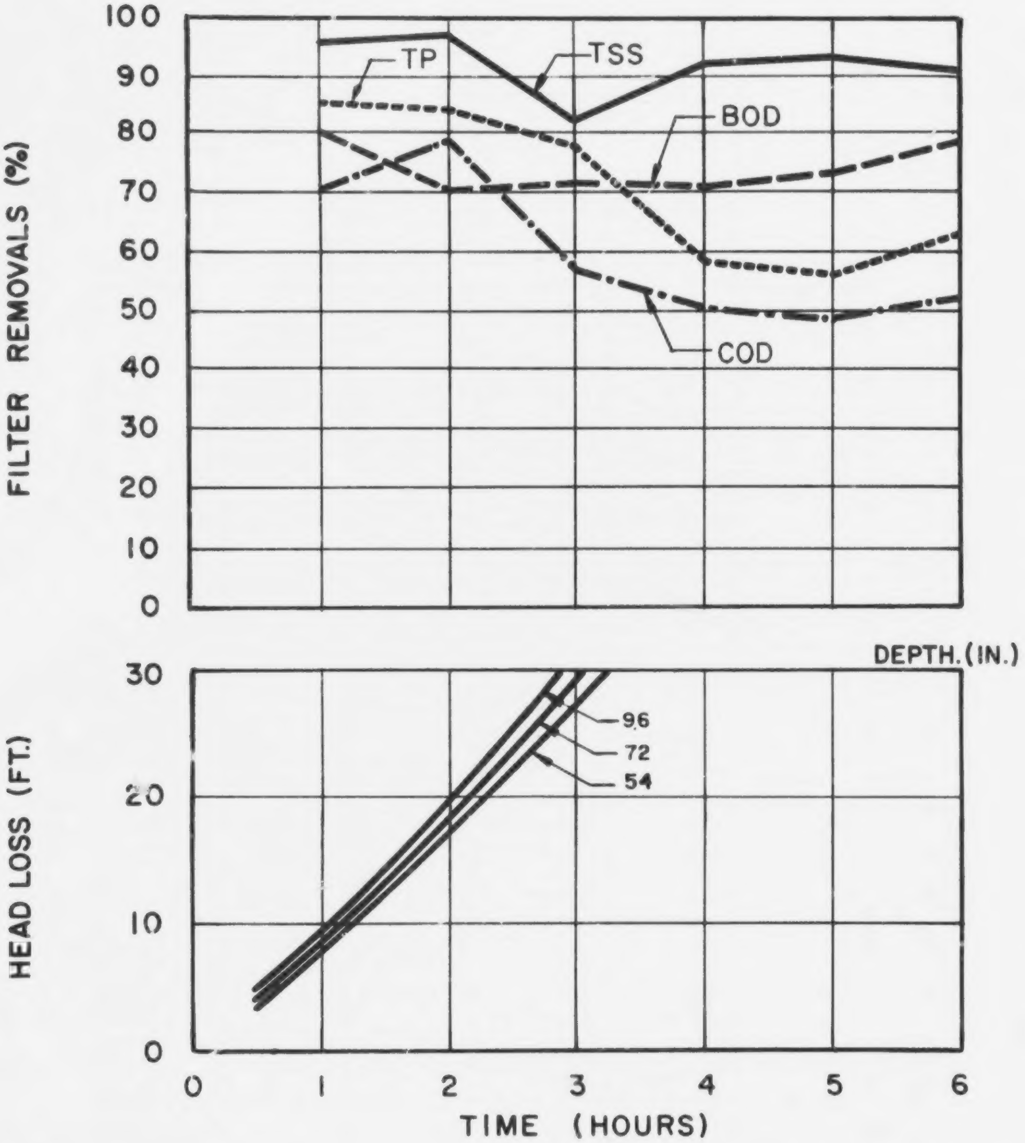
DATE 7/24/71 FLUX RATE 24 gpm/ft$^2$ COAG. 0 mg/l

POLY. ATLA 4A4 1.0 mg/l

RUN No. 23SFIV

COMBINED SEWER OVERFLOW FILTRATION TEST

FIGURE C125



SCREEN 40 MESH. FILTER MEDIA 60 in. No. 3 ANTH./ 36 in. No. 612 SAND

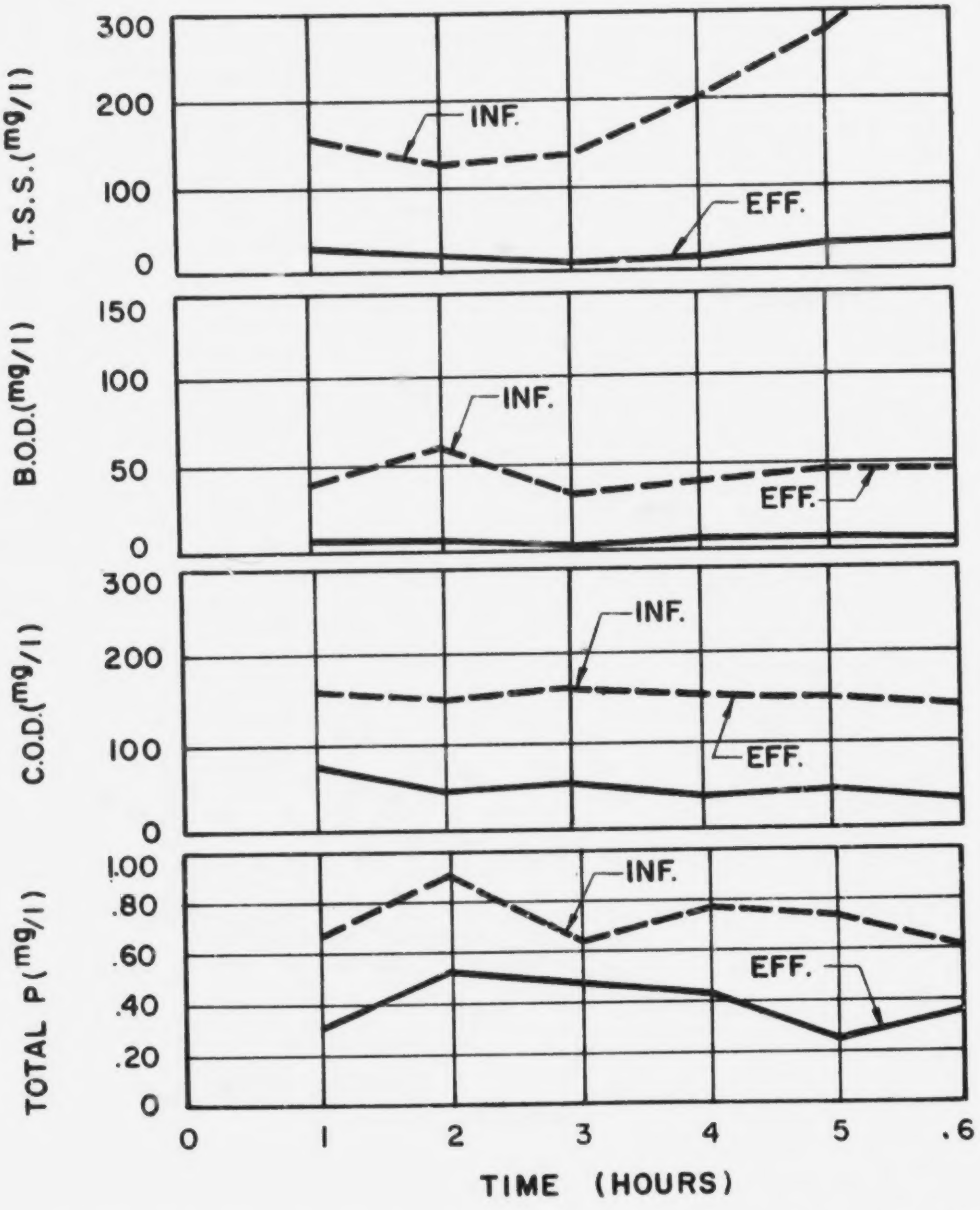
DATE 7/24/71 FLUX RATE 24 gpm/ft$^2$ COAG 0 mg/l

POLY. ATLA 4A4 1.0 mg/l

RUN No. 23SFIV

COMBINED SEWER OVERFLOW FILTRATION TEST

FIGURE C126



SCREEN 40 MESH. FILTER MEDIA 60 in. No. 3 ANTH./36 in. No. 612 SAND

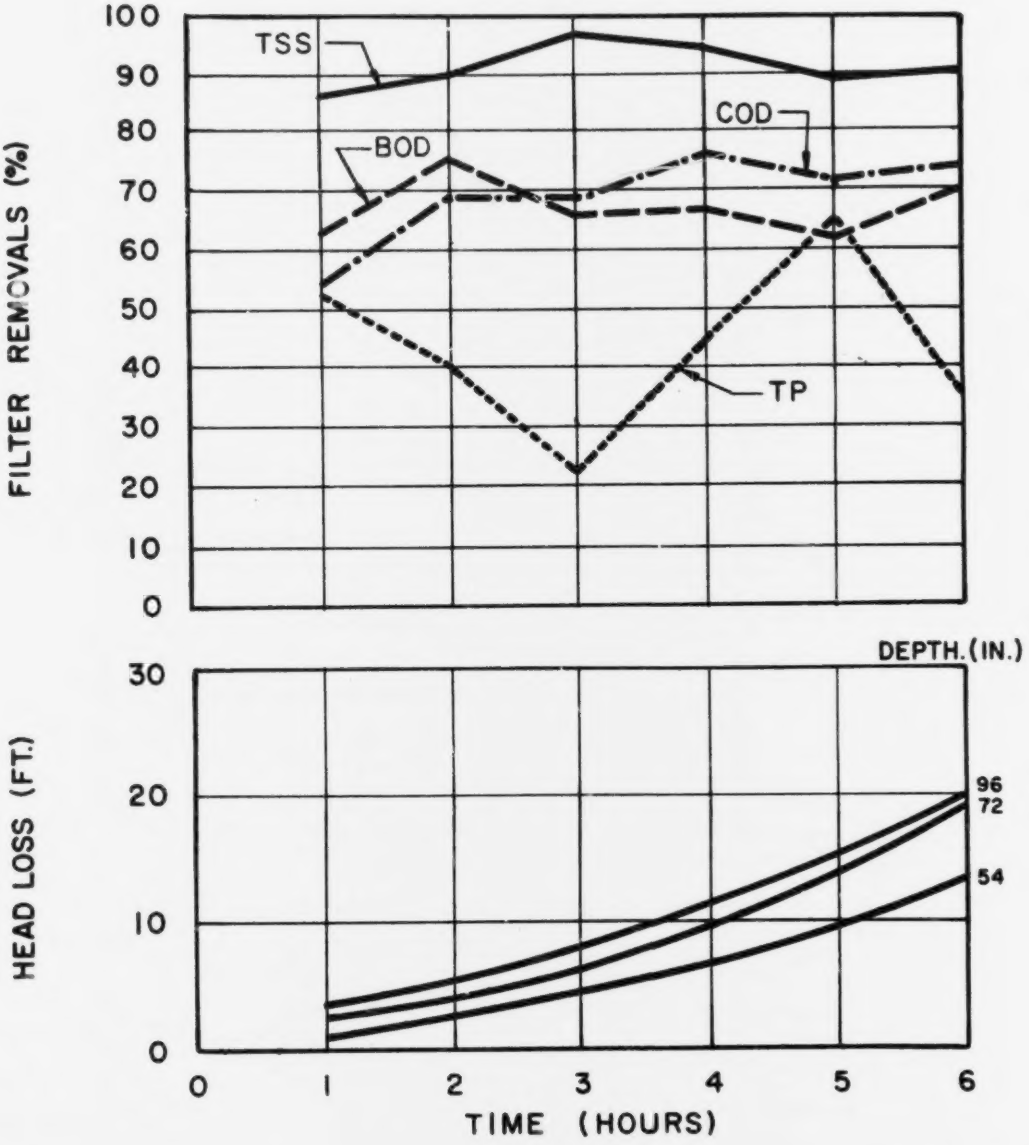
DATE 7/24/71 FLUX RATE 24 gpm/ft$^2$ COAG. 0 mg/l

POLY. PURIFL.A-23, 1.0 mg/l

RUN No. 23ASFII

## COMBINED SEWER OVERFLOW FILTRATION TEST

FIGURE C127



SCREEN 40 MESH. FILTER MEDIA 60 in. No. 3 ANTH./ 36 in. No. 612 SAND

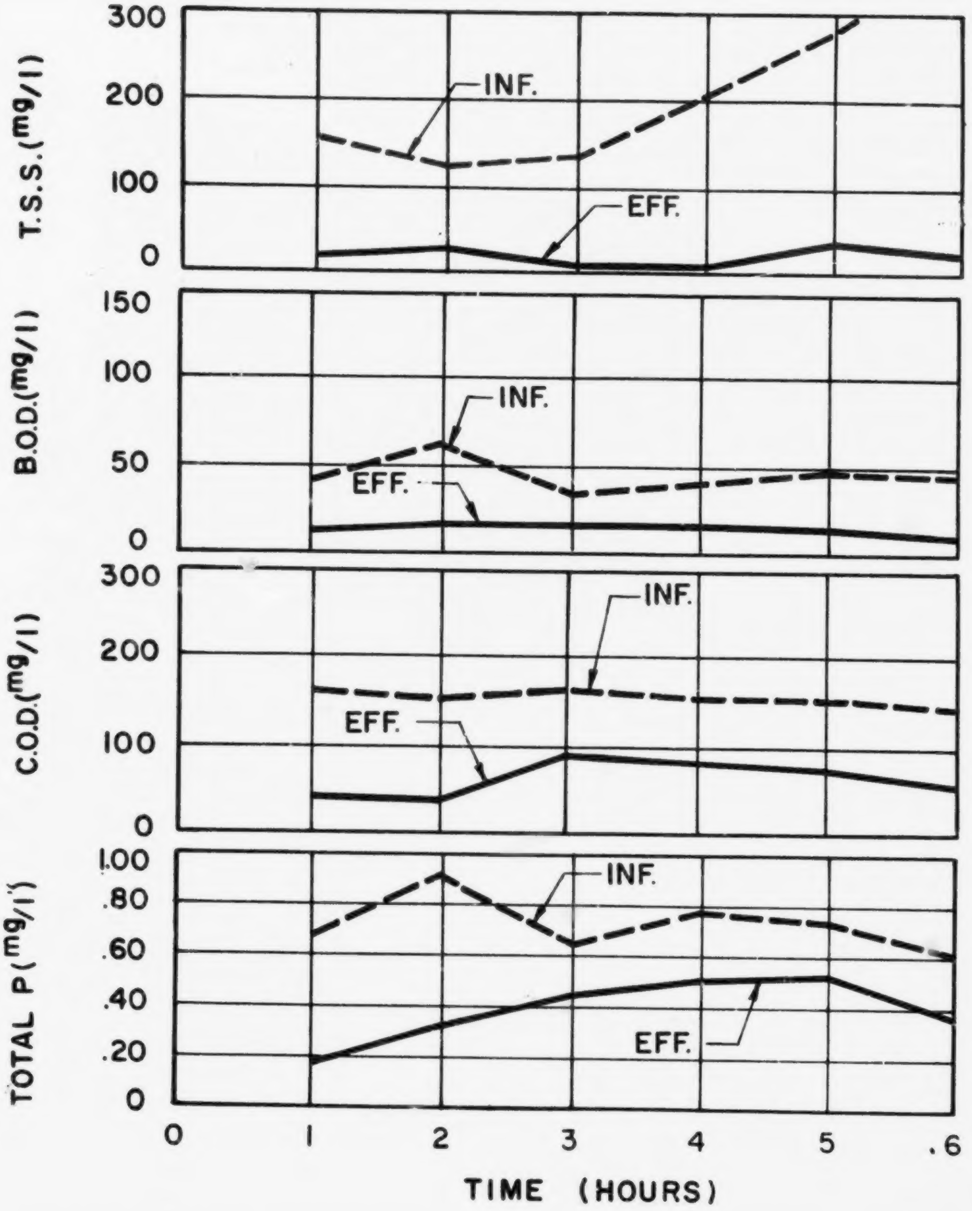
DATE 7/24/71 FLUX RATE 24 gpm/ft$^2$ COAG. 0 mg/l

POLY. PURIFL. A-23 1.0 mg/l

RUN No. 23ASF11

**COMBINED SEWER OVERFLOW FILTRATION TEST**

**FIGURE C128**



SCREEN 40 MESH. FILTER MEDIA 60 in. No. 3 ANTH./36 in. No. 612 SAND

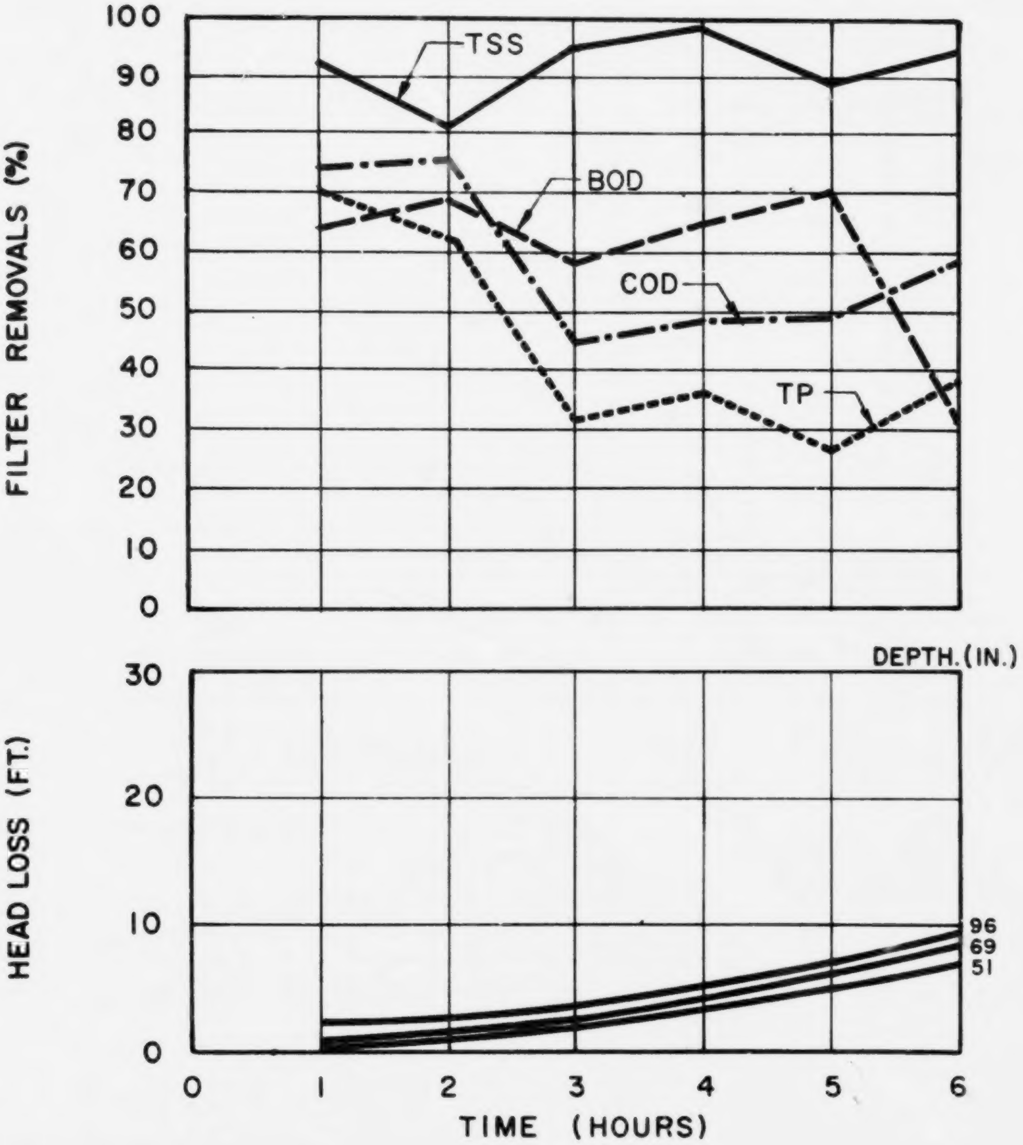
DATE 7/24/71 FLUX RATE 16 gpm/ft$^2$ COAG. 0 mg/l

RUN No. 23ASF III

POLY. PURIFL. A-23, 1.0 mg/l

**COMBINED SEWER OVERFLOW FILTRATION TEST**

FIGURE C129



SCREEN 40 MESH. FILTER MEDIA 60 in. No. 3 ANTH./36 in. No. 612 SAND

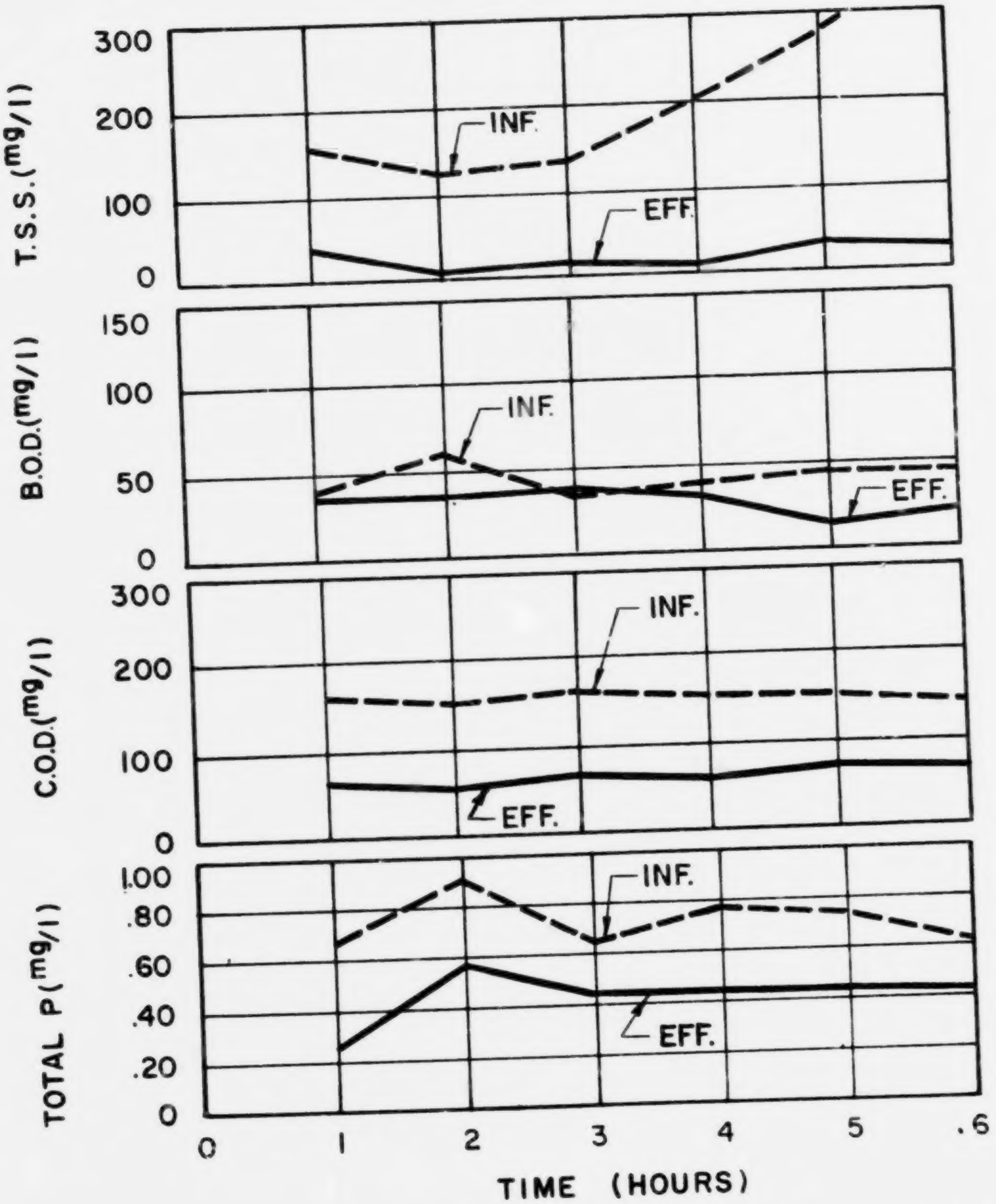
DATE 7/24/71 FLUX RATE 16 gpm/ft² COAG. 0 mg/l

POLY PURIFL A-23, 1.0 mg/l

RUN No. 23ASFIV

COMBINED SEWER OVERFLOW FILTRATION TEST

FIGURE C130



SCREEN 40 MESH. FILTER MEDIA 60 in. No. 3 ANTH./36 in. No. 612 SAND

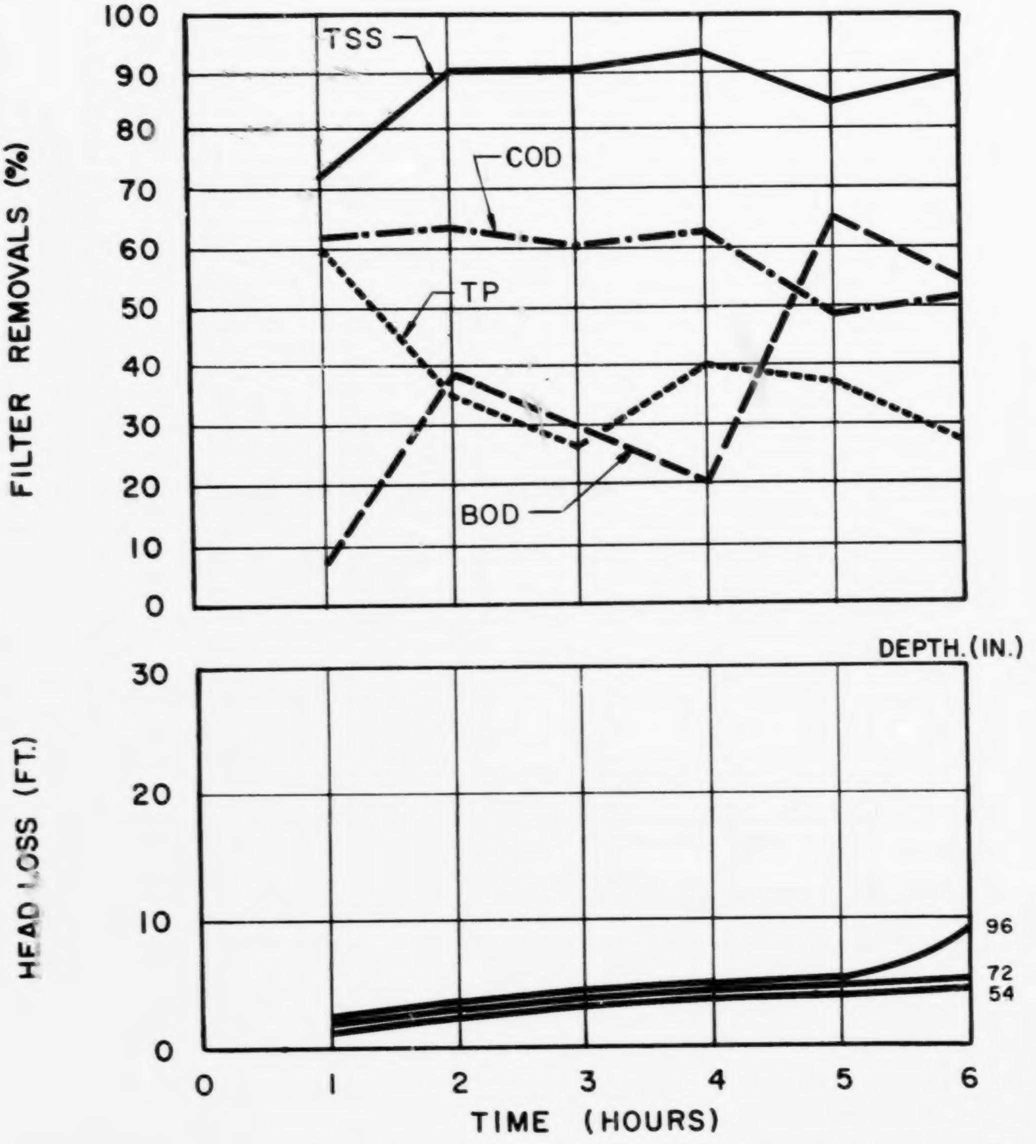
DATE 7/24/71 FLUX RATE 8 gpm/ft$^2$ COAG. 0 mg/l

POLY. PURIFL. A-23, 1.0 mg/l

RUN No. 23ASFIII

COMBINED SEWER OVERFLOW FILTRATION TEST

FIGURE C131



SCREEN 40 MESH. FILTER MEDIA 60 in. No. 3 ANTH./36 in. No. 612 SAND

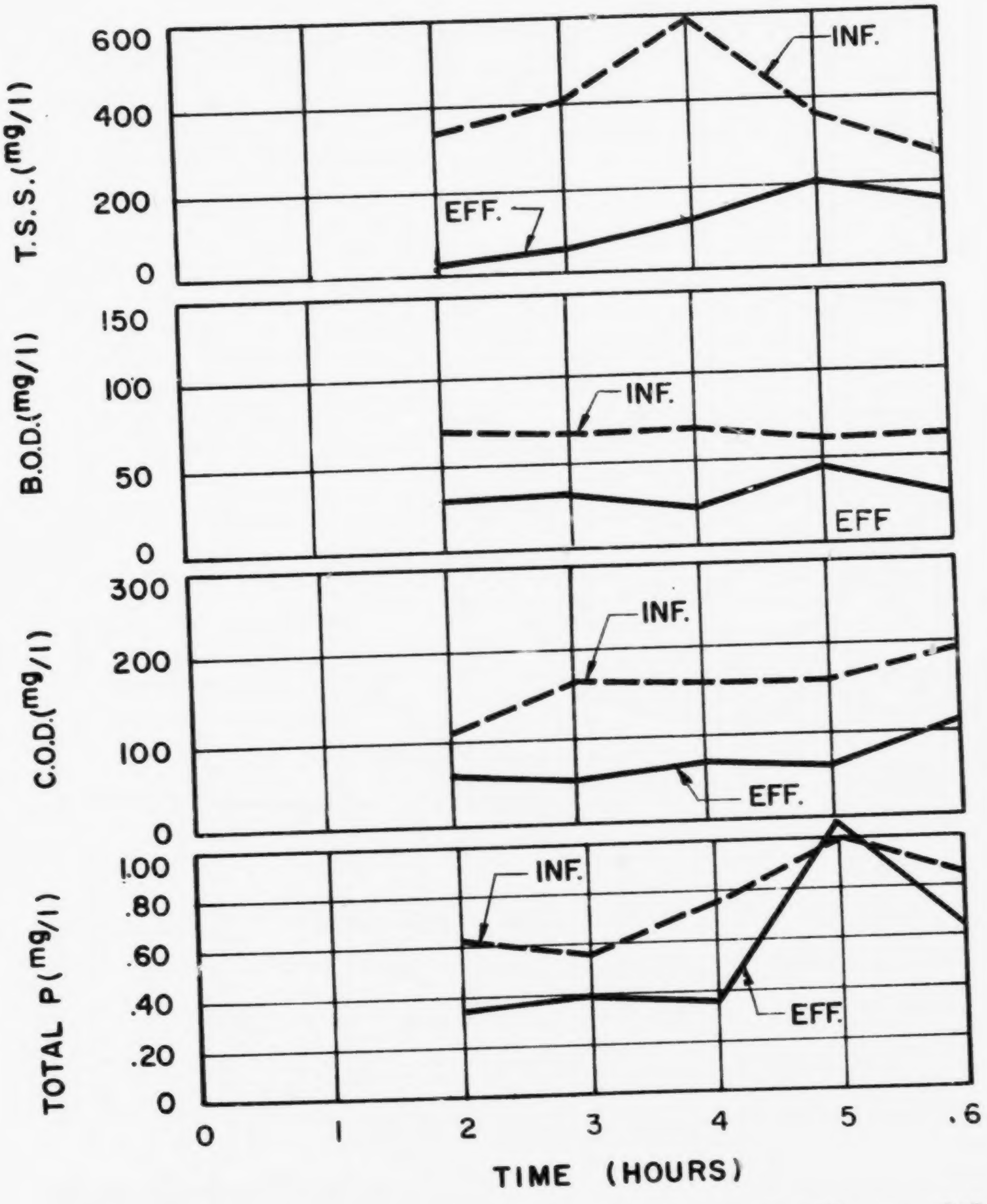
DATE 7/24/71 FLUX RATE 8 gpm/ft² COAG. 0 mg/l

POLY PURIFL. A-23, 1.0 mg/l

RUN No. 23ASFIV

COMBINED SEWER OVERFLOW FILTRATION TEST

FIGURE C132



SCREEN 40 MESH. FILTER MEDIA 60 in. No. 3 ANTH./36 in. No. 612 SAND

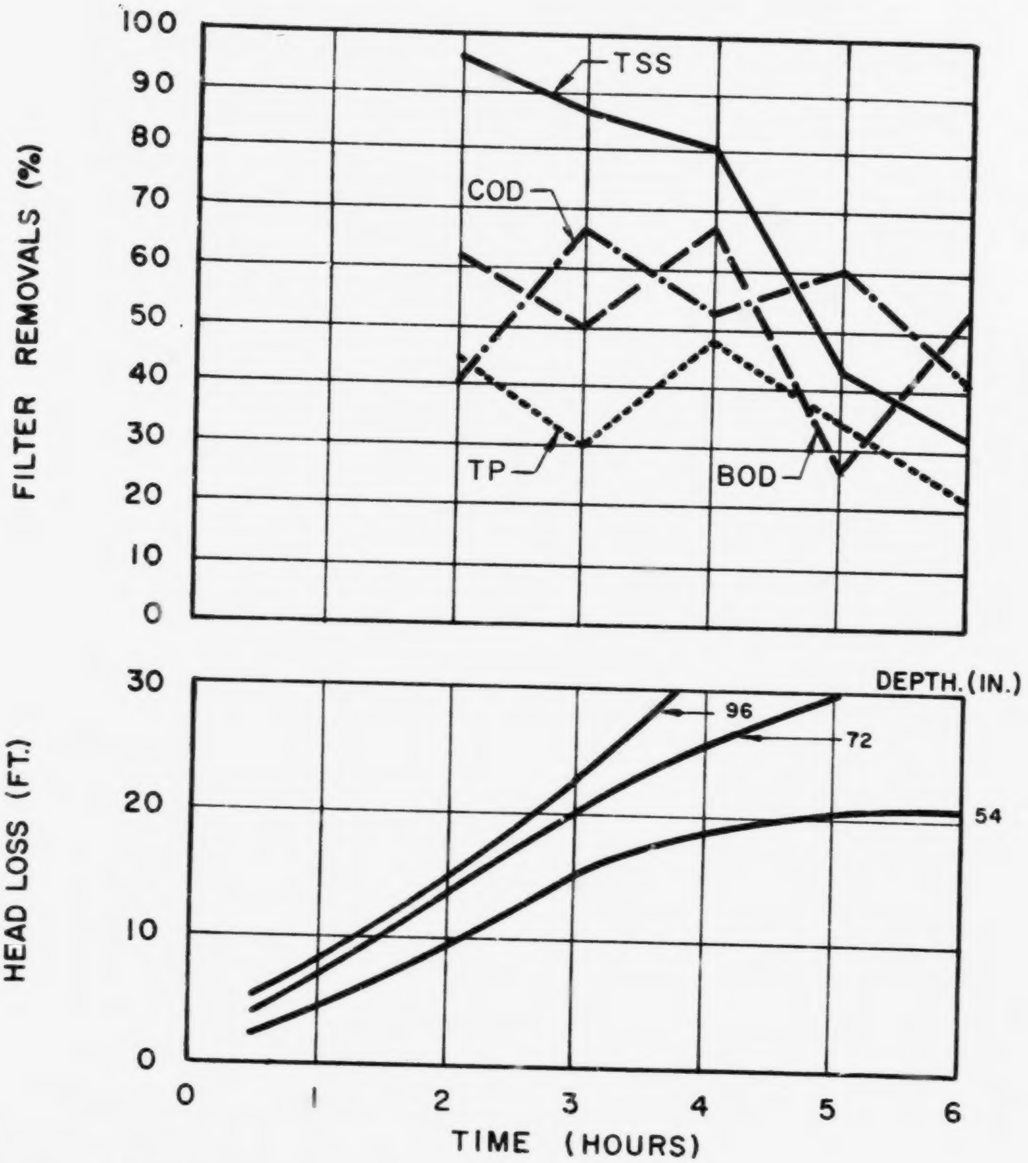
DATE 7/26/71 FLUX RATE 24 gpm/ft² COAG. 0 mg/l

POLY. MAG. 560 C 1.0 mg/l

RUN No. 23BSFII

COMBINED SEWER OVERFLOW FILTRATION TEST

FIGURE C133



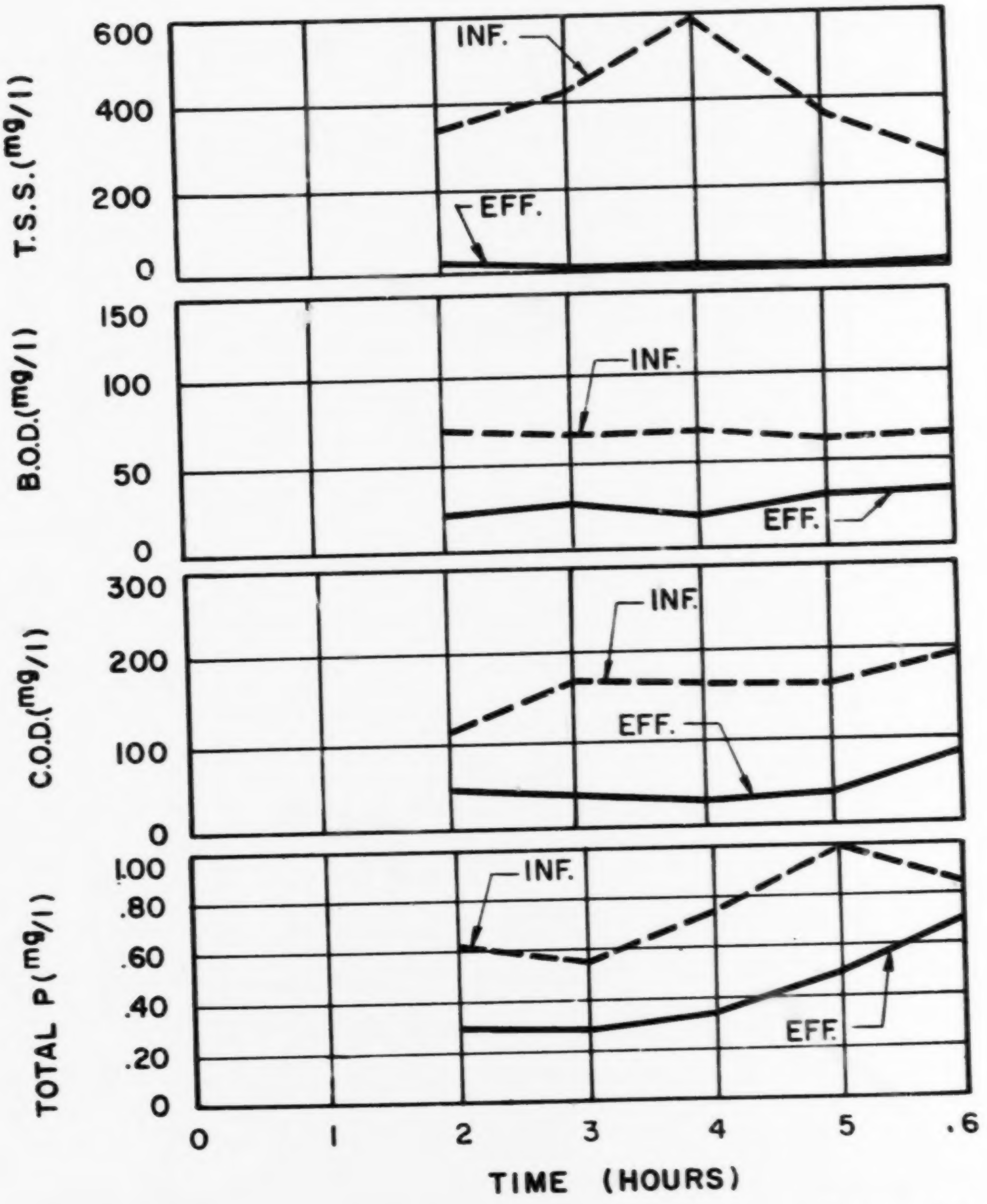
SCREEN 40 MESH. FILTER MEDIA 60 in. No. 3 ANTH./36 in. No. 612 SAND

DATE 7/26/71 FLUX RATE 24 gpm/ft² COAG. 0 mg/l

RUN No. 23BSF11 POLY. MAG. 560C 1.0 mg/l

COMBINED SEWER OVERFLOW FILTRATION TEST

FIGURE C134



SCREEN 40 MESH. FILTER MEDIA 60 in. No. 3 ANTH./36 in. No. 612 SAND

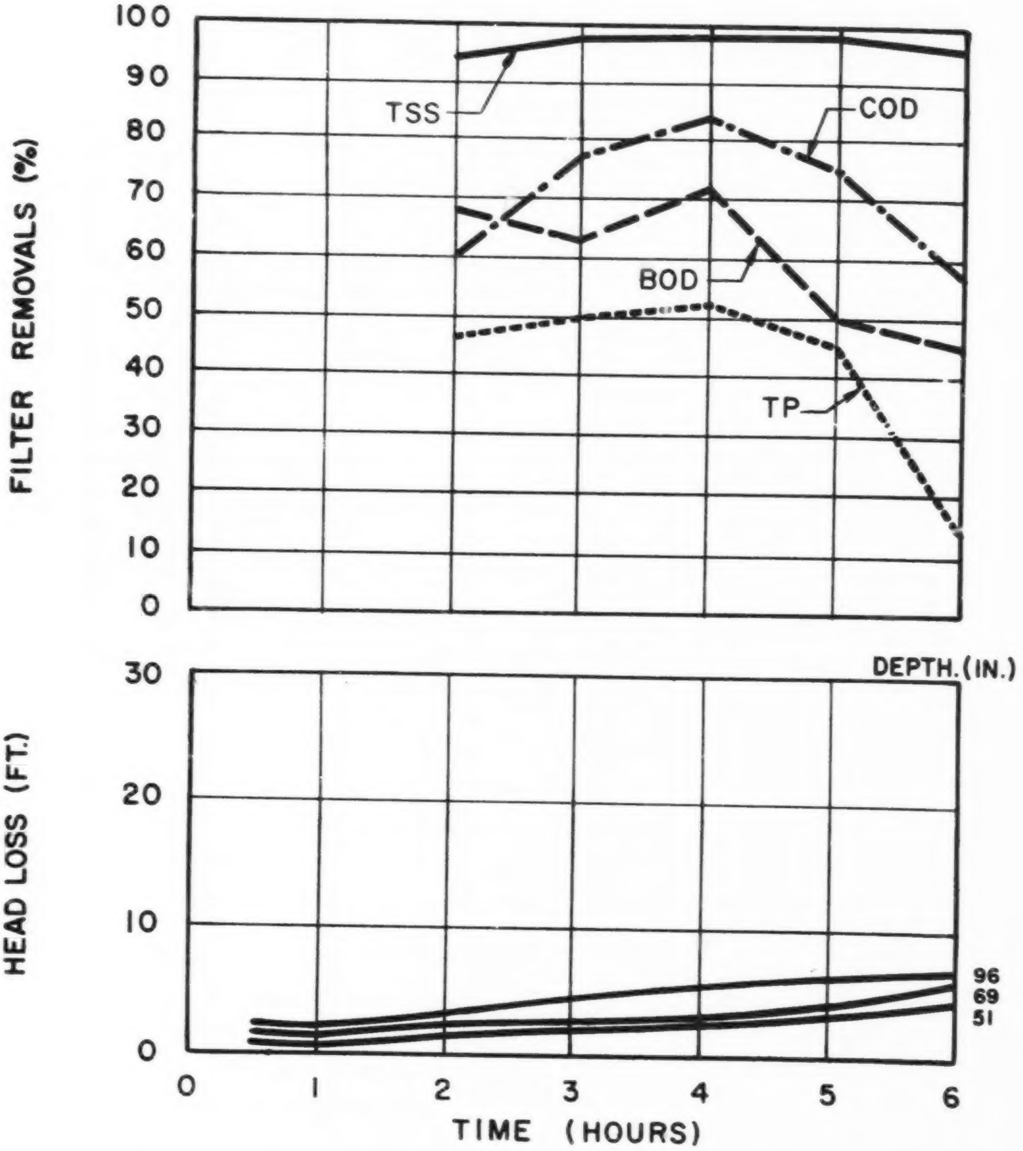
DATE 7/26/71 FLUX RATE 8 gpm/ft$^2$ COAG. 0 mg/l

POLY. MAG. 560C 1.0 mg/l

RUN No. 23BSFIII

COMBINED SEWER OVERFLOW FILTRATION TEST

FIGURE C135



SCREEN 40 MESH. FILTER MEDIA 60 in. No. 3 ANTH./36 in. No. 612 SAND

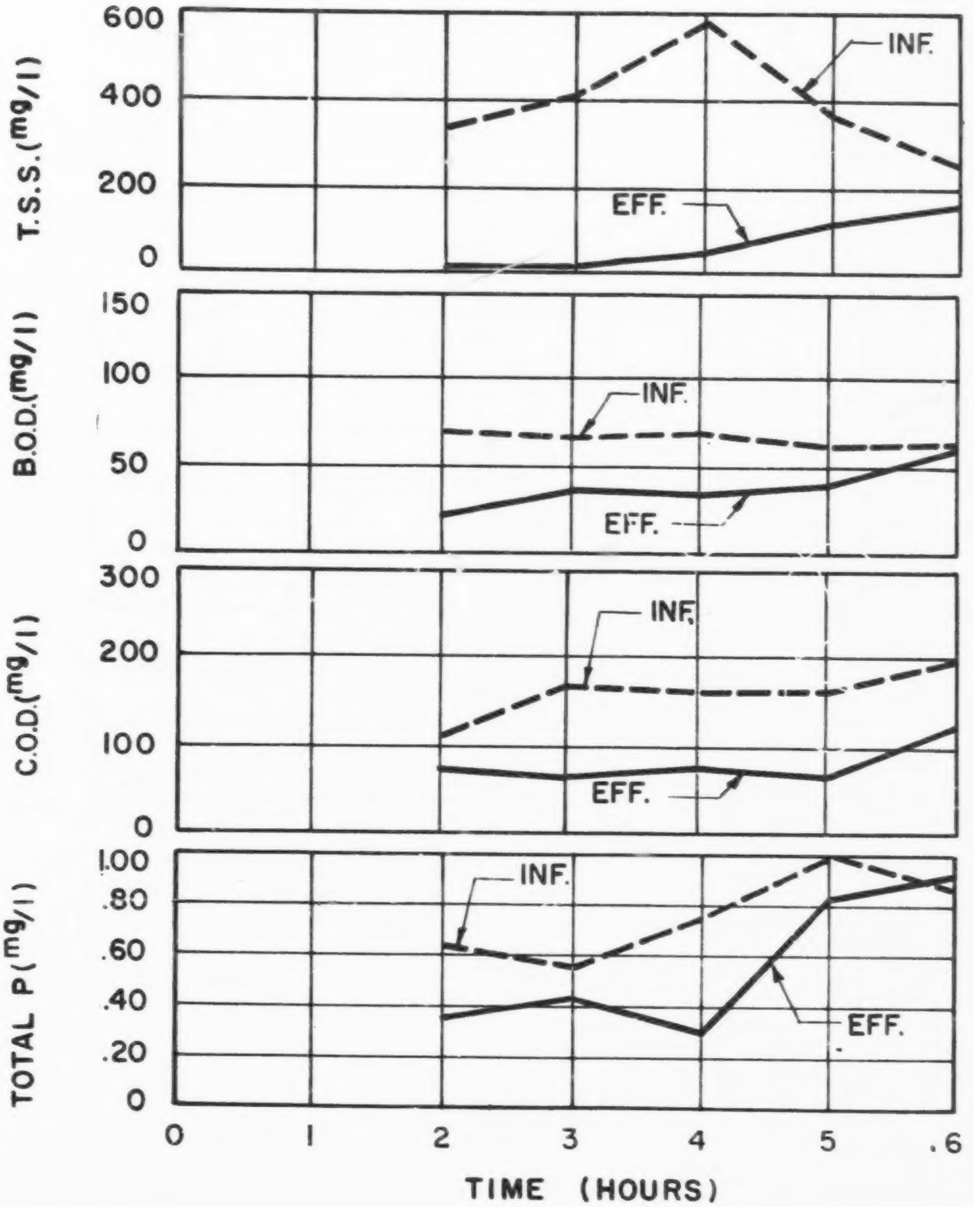
DATE 7/26/71 FLUX RATE 8 gpm/ft$^2$ COAG. 0 mg/l

POLY. MAG. 560C 1.0 mg/l

RUN No. 23BSFIII

COMBINED SEWER OVERFLOW FILTRATION TEST

FIGURE C136



SCREEN 40 MESH. FILTER MEDIA 60 in. No. 3 ANTH. / 36 in. No. 612 SAND

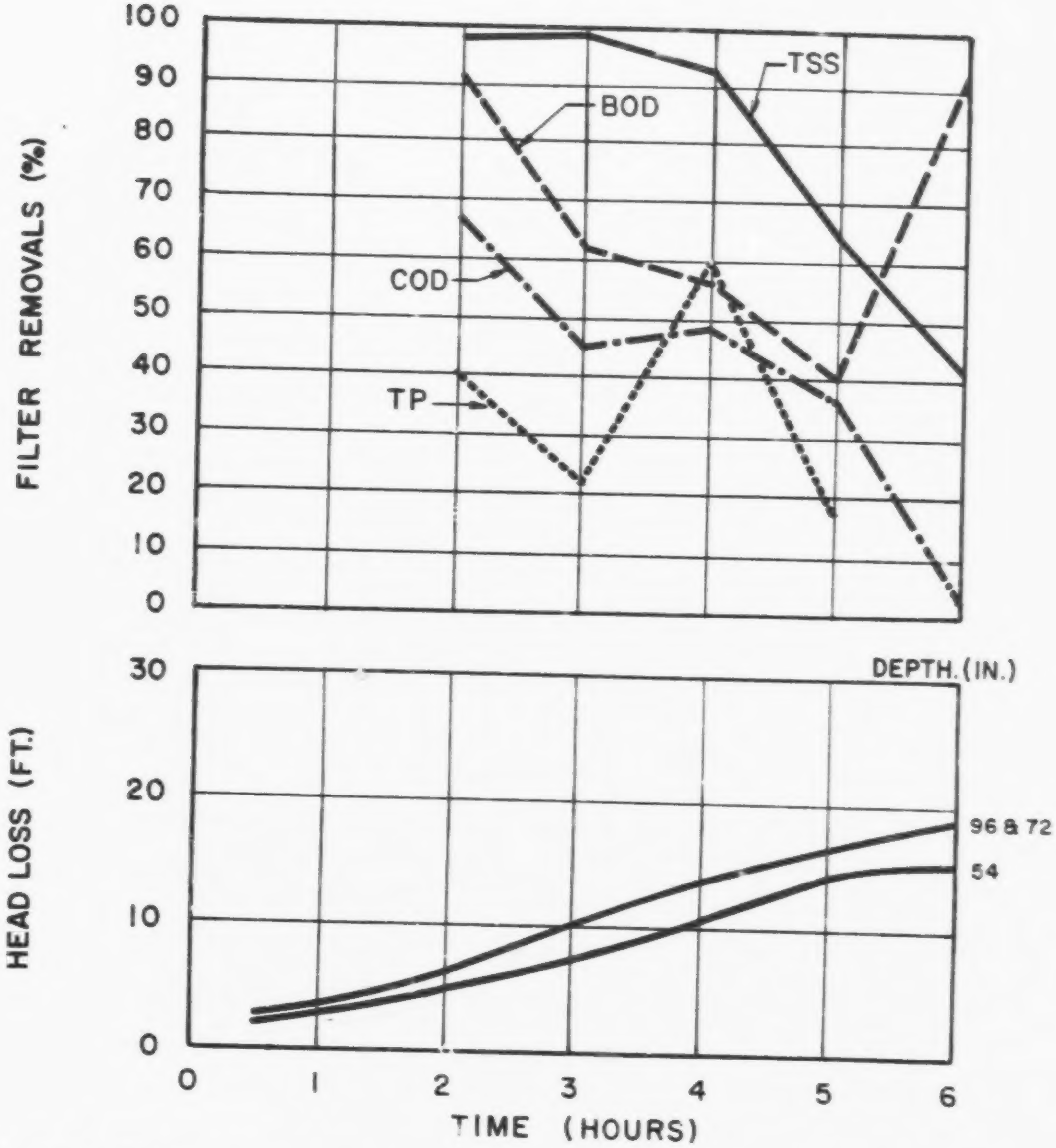
DATE 7/26/71 FLUX RATE 16 gpm/ft$^2$ COAG. 0 mg/l

POLY. MAG. 560 C 1.0 mg/l

RUN No. 23BSFIV

## COMBINED SEWER OVERFLOW FILTRATION TEST

FIGURE C137



SCREEN 40 MESH. FILTER MEDIA 60 in. No. 3 ANTH./36 in. No. 612 SAND

DATE 7/26/71 FLUX RATE 16 gpm/ft² COAG. 0 mg/l

POLY. MAG. 560C1.0 mg/l

RUN No. 23BSFIV

COMBINED SEWER OVERFLOW FILTRATION TEST

FIGURE C138

# APPENDIX D

## HIGH RATE FILTRATION OF SECONDARY EFFLUENT

In addition to the major emphasis of the testing project at Cleveland, that is, treatment of combined sewer overflows, a series of tests were conducted on secondary effluent from the Southerly Wastewater Treatment Plant. Twenty test column runs were performed on secondary effluent. The media utilized in the testing was as follows:

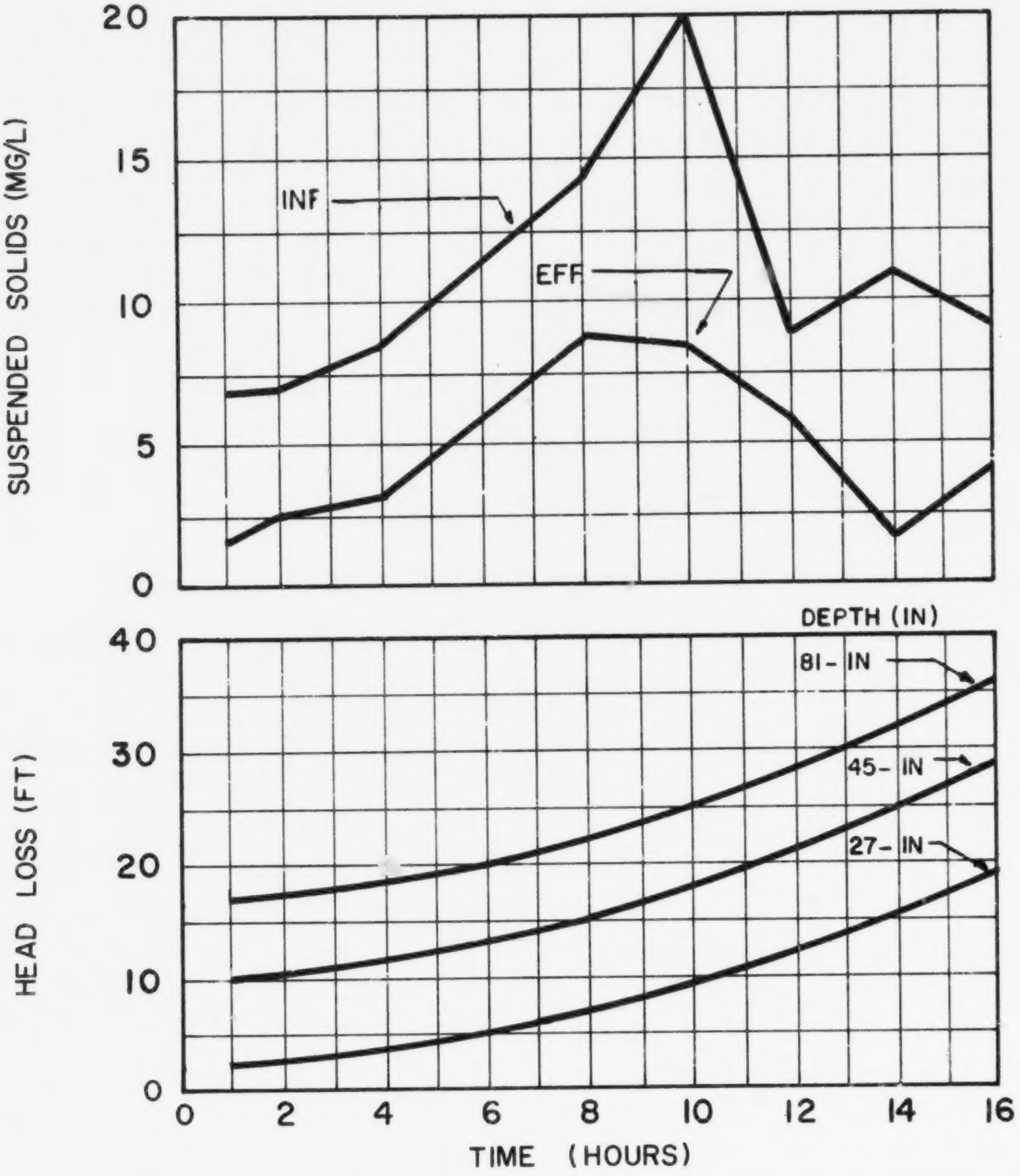
| Filter Media | Effective Size (mm) | Uniformity Coefficient |
|---|---|---|
| No. 1 Anthracite | 0.66 | 1.62 |
| No. 1 1/2 Anthracite | 0.98 | 1.73 |
| No. 2 Anthracite | 1.78 | 1.63 |
| No. 1220 Sand | 0.95 | 1.41 |
| No. 2050 Sand | 0.45 | 1.33 |

Summarized results of the testing are indicated in Table D1. Data curves for all the test runs are indicated in Figures D1 through D19. Media combinations utilized included: 48 inches of No. 1 Anthracite over 36 inches of No. 2050 Sand, 48 inches of No. 1 1/2 Anthracite over 36 inches of No. 2050 Sand, and 48 inches of No. 2 Anthracite over 36 inches of No. 2050 Sand. In some of the test runs, alum and polyelectrolyte were also utilized. Filtration rates tested range from 10 gpm/sq ft to 30 gpm/sq ft. A run was attempted at 45 gpm/sq ft, but was discontinued when the pressure loss (head loss) generated through the filter media was beyond range of readings obtainable in the test column gauges.

The five media combinations mentioned were evaluated under runs 1SE through runs 10SE, as shown in Table D1. Unfortunately, due to the low influent suspended solids levels, it is difficult to draw any conclusions regarding the various media.

The combination of 48 inches of No. 1 1/2 Anthracite over 36 inches of No. 1220 Sand was selected for testing in conjunction with the chemical additives. The range of influent suspended solids during these six final test runs was in a higher range than had been experienced in the testing program. The three column runs performed under the 11 SE test series had an average influent suspended solids of 13.7 mg/1, with a maximum of 32 mg/1. The influent solids level in test series 12 SE was 18.4 mg/1. of suspended solids, with a maximum of 40 mg/1 of suspended solids. These solids levels are representative of a situation where a filter might be applicable. Polyelectrolyte and alum were added to the filter influent in both series 11 SE and 12 SE. In test series 11 SE, 0.5 mg/l polyelectrolyte was added plus 5 mg/l of alum; and in Series 12 SE, 1 mg/l of polyelectrolyte and 5 mg/l of alum were added. In these last six test runs, utilizing chemical addition, the high rate filter produced suspended solids consistently below 10 mg/l throughout the test run, as shown in the data curves. Even more interesting is the fact that changing the filtration rate from 10 gpm/sq.ft. to 30 gpm/sq.ft. had a negligible effect on the performance of the filter, as evidenced by the average effluent quality values for the test runs. Average effluent quality approximated 4 to 6 mg/l.

To summarize, the most important conclusion evidenced from this test data is that, with chemical addition, effluent suspended solids can be controlled to below 10 mg/l at filtration rates of 30 gpm/sq ft and with lengths of filter runs in excess of four hours. Head loss experienced during these latter filtration tests with chemicals varied from 6.5 to 35.5 feet.



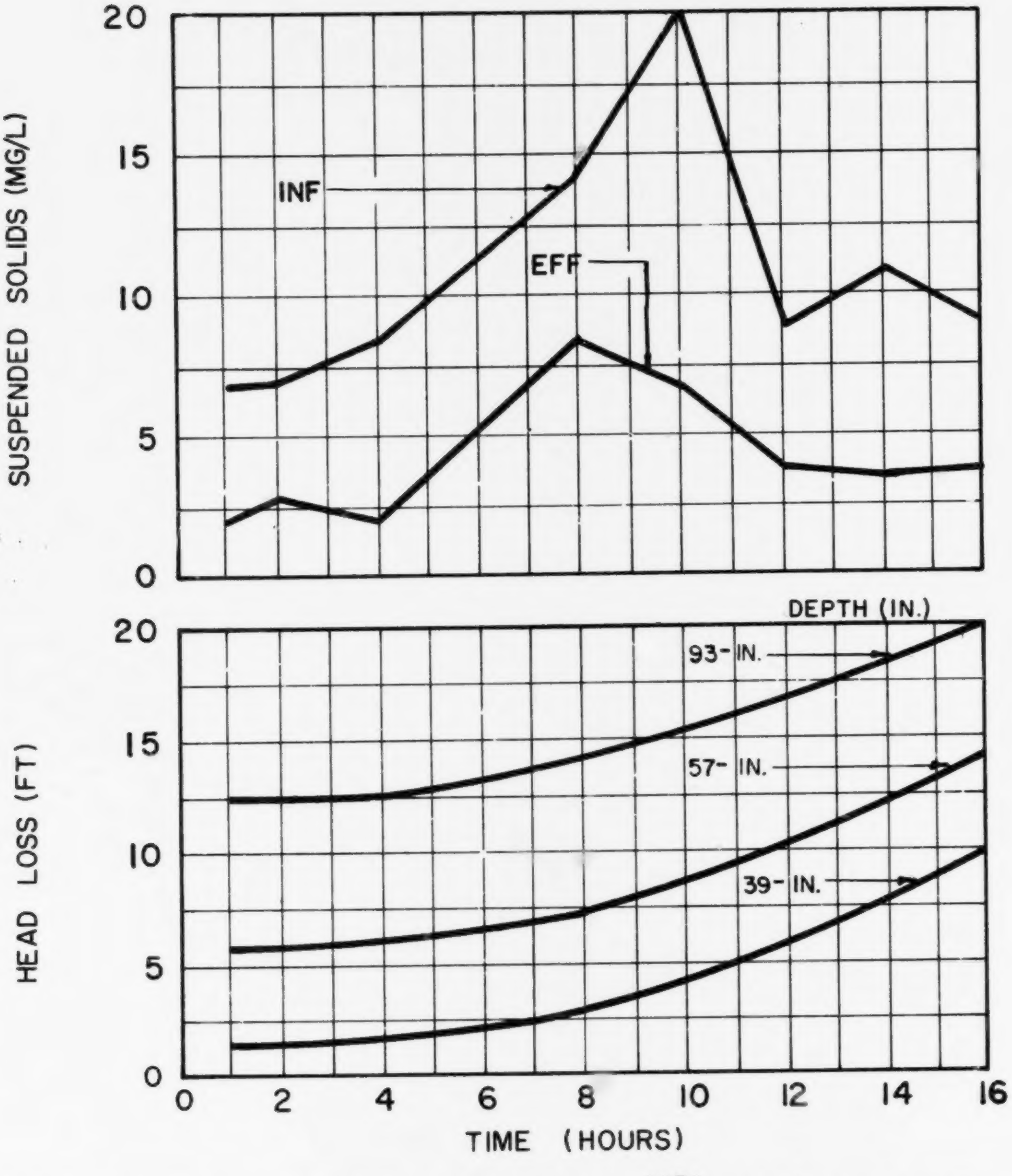
FILTER MEDIA 48 in. No. 1 1/2 ANTH./36 in No. 2050 SAND/18 in. GRAVEL

DATE 8/7/70 FLUX RATE 24 gpm/ft$^2$

RUN No. ISEII

## SECONDARY EFFLUENT FILTRATION TEST

FIGURE D1



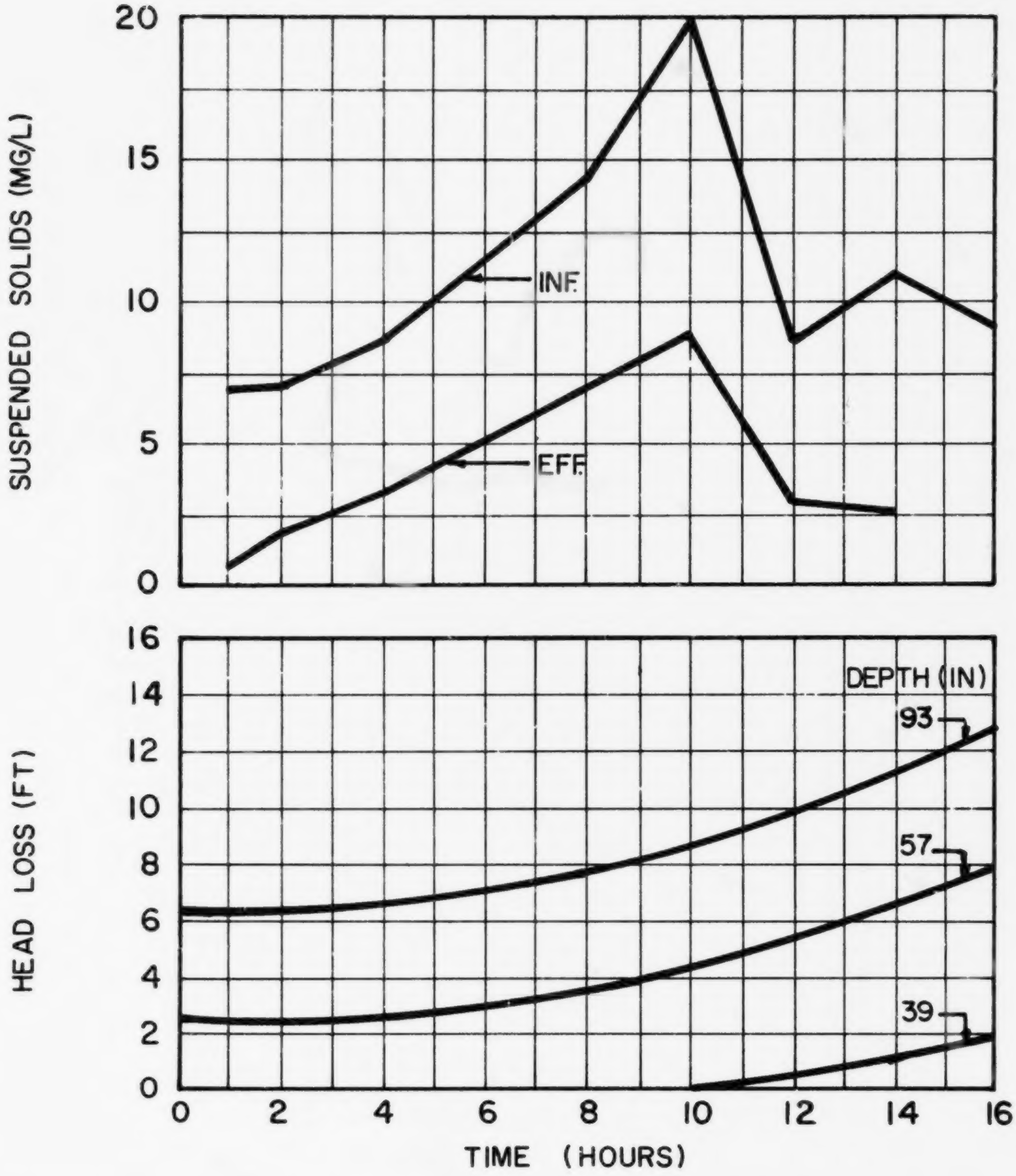
FILTER MEDIA 48 in. No. 1 1/2 ANTH./36 in No. 2050 SAND/18 in. GRAVEL

DATE 8/7/70 FLUX RATE 16 gpm/ft$^2$

RUN No. ISEIII

SECONDARY EFFLUENT FILTRATION TEST

FIGURE D 2



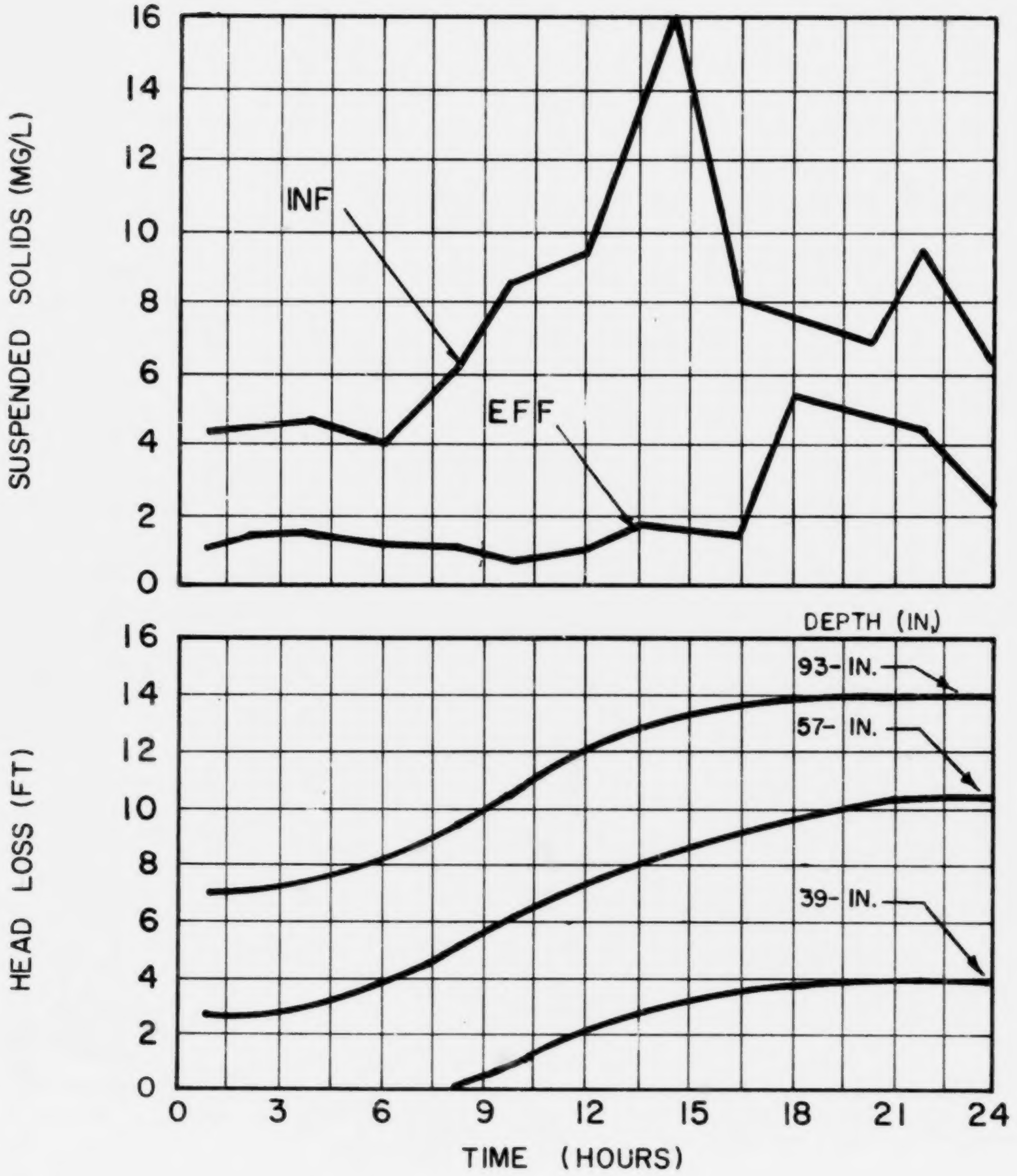
FILTER MEDIA: 48 in. No. 1 1/2 ANTH./ 36 in No. 2050 SAND/18 in. GRAVEL

DATE 8/7/70 FLUX RATE 10 gpm/ft$^2$

RUN No. 1SEIV

SECONDARY EFFLUENT FILTRATION TEST

FIGURE D 3



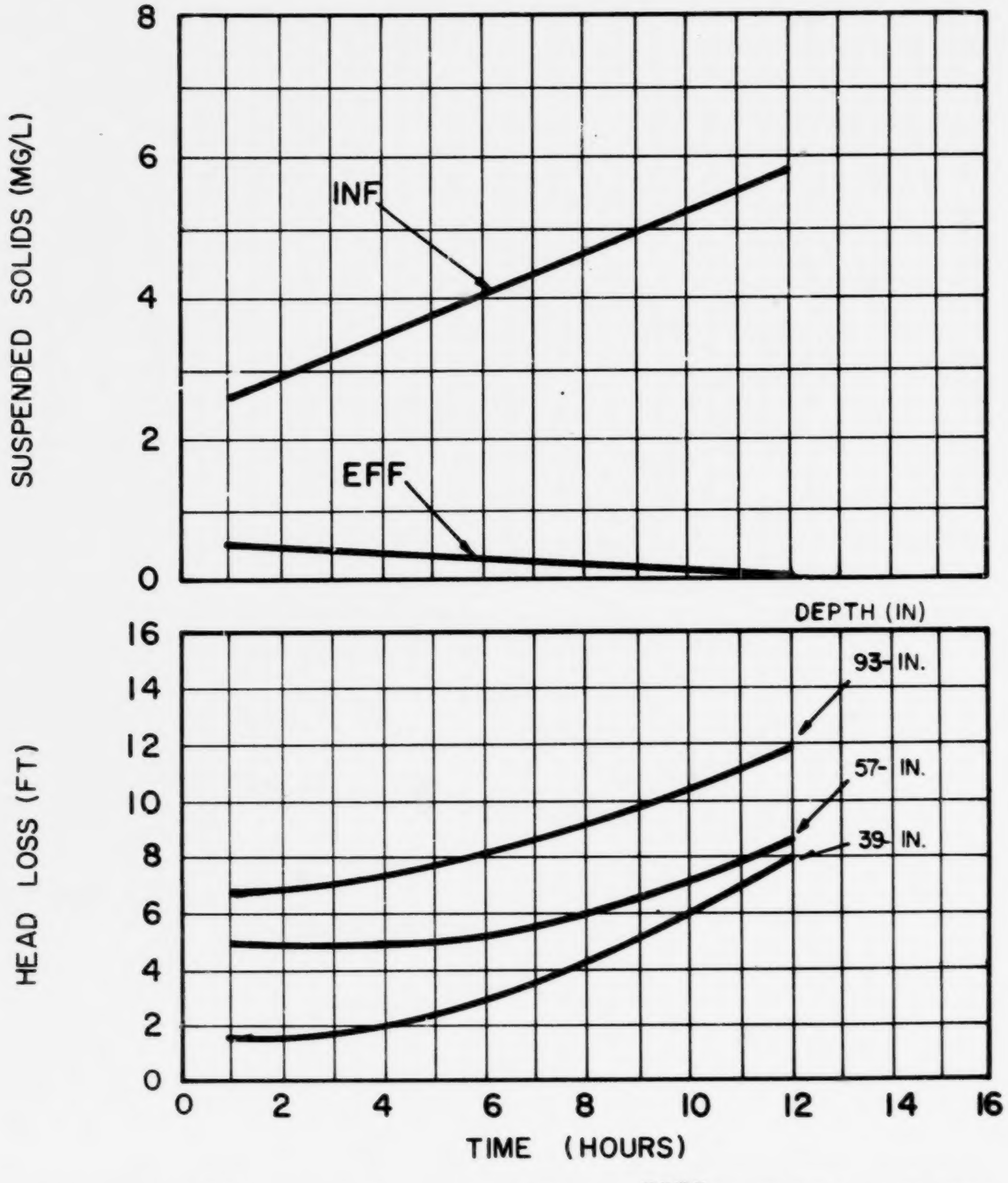
FILTER MEDIA 48 in. No. 1 1/2 ANTH./ 36 in No. 2050 SAND/18 in. GRAVEL

DATE 8/18/70 FLUX RATE 10 $\text{gpm/ft}^2$

RUN No 2SEIV

SECONDARY EFFLUENT FILTRATION TEST

FIGURE D 4



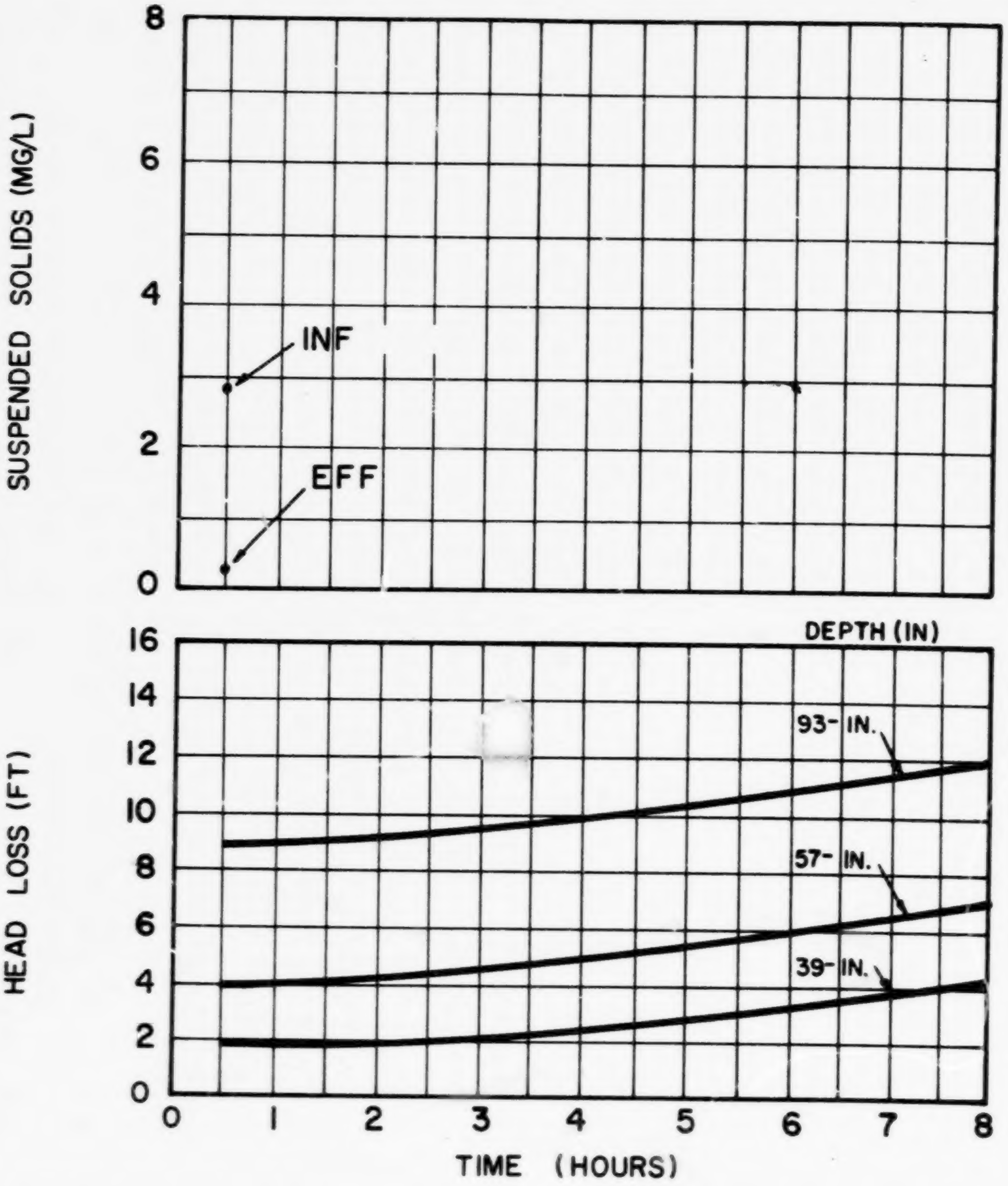
FILTER MEDIA 48 in. No. 1 ANTH./36 in No. 2050 SAND/18 in. GRAVEL

DATE 9/14/70 FLUX RATE 10 gpm/ft$^2$

RUN No. **3SEIV**

SECONDARY EFFLUENT FILTRATION TEST

FIGURE D 5



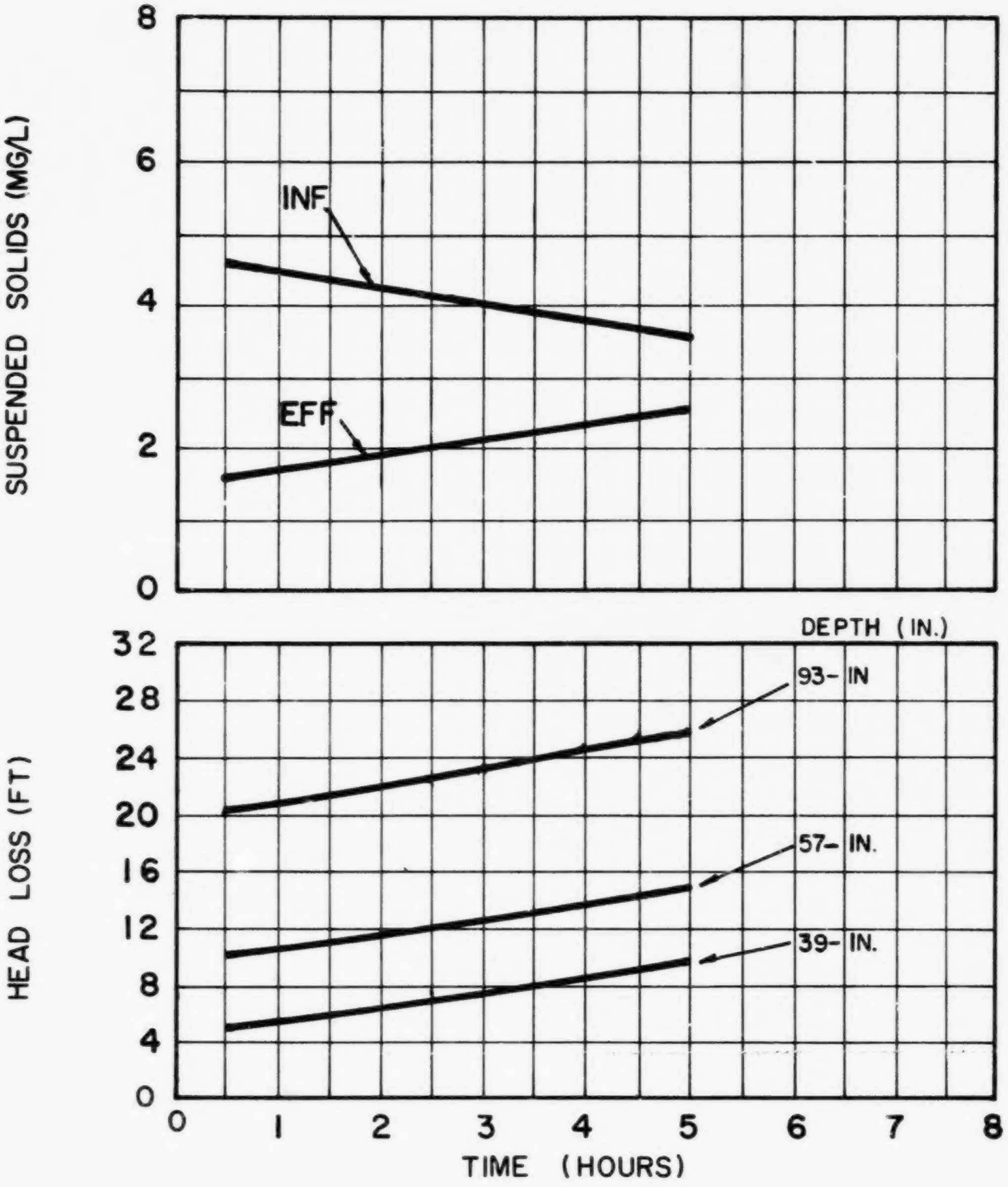
FILTER MEDIA 48 in. No. 1 ANTH./ 36 in No. 2050 SAND/18 in. GRAVEL

DATE 9/15/70 FLUX RATE 15 gpm/ft$^2$

RUN No. 4SEIV

SECONDARY EFFLUENT FILTRATION TEST

FIGURE D 6



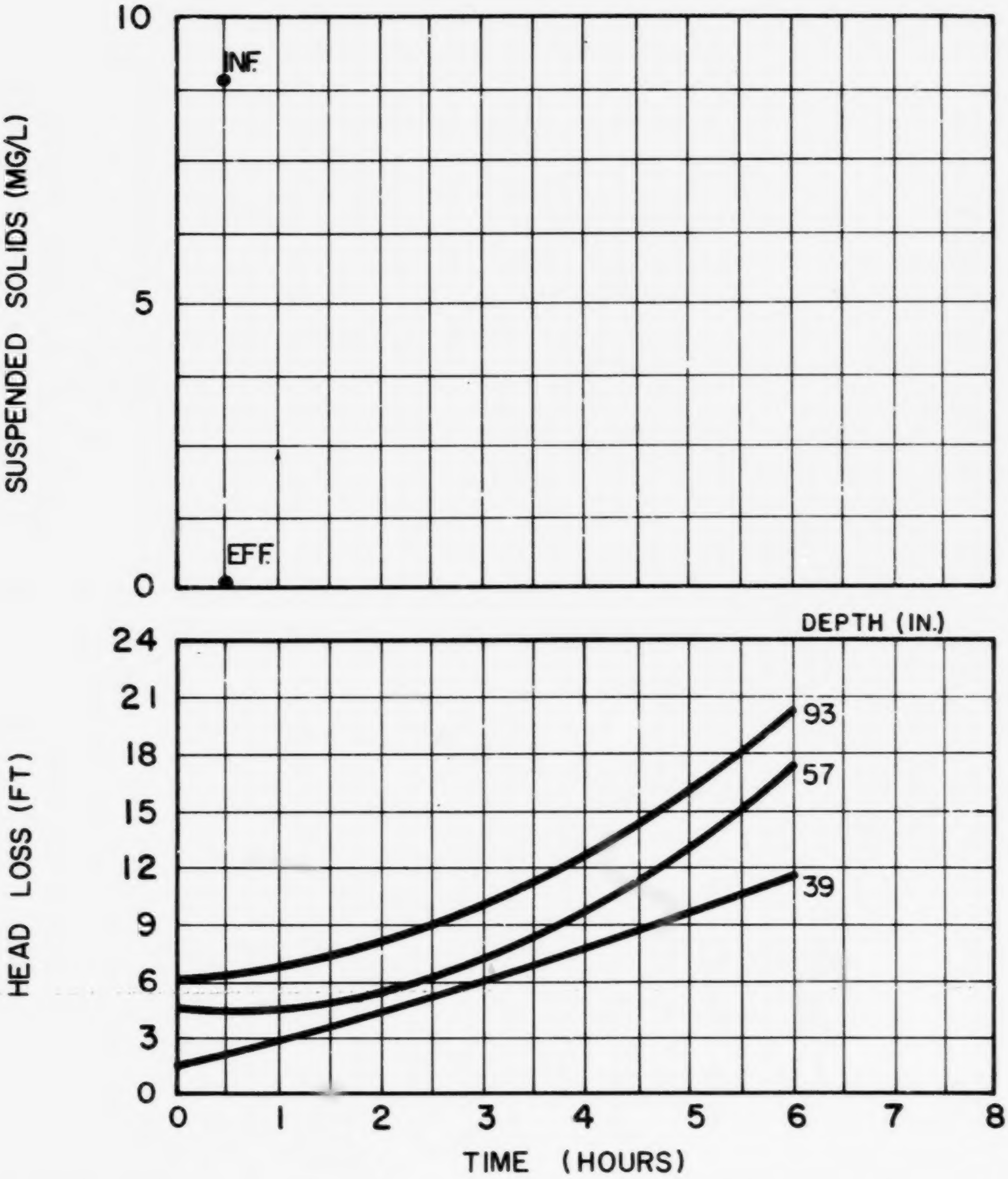
FILTER MEDIA 48 in. No. 1 ANTH./36 in No. 2050 SAND/18 in. GRAVEL

DATE 9/16/70 FLUX RATE 30 gpm/ft$^2$

RUN No. 5SEIV

**SECONDARY EFFLUENT FILTRATION TEST**

**FIGURE D 7**



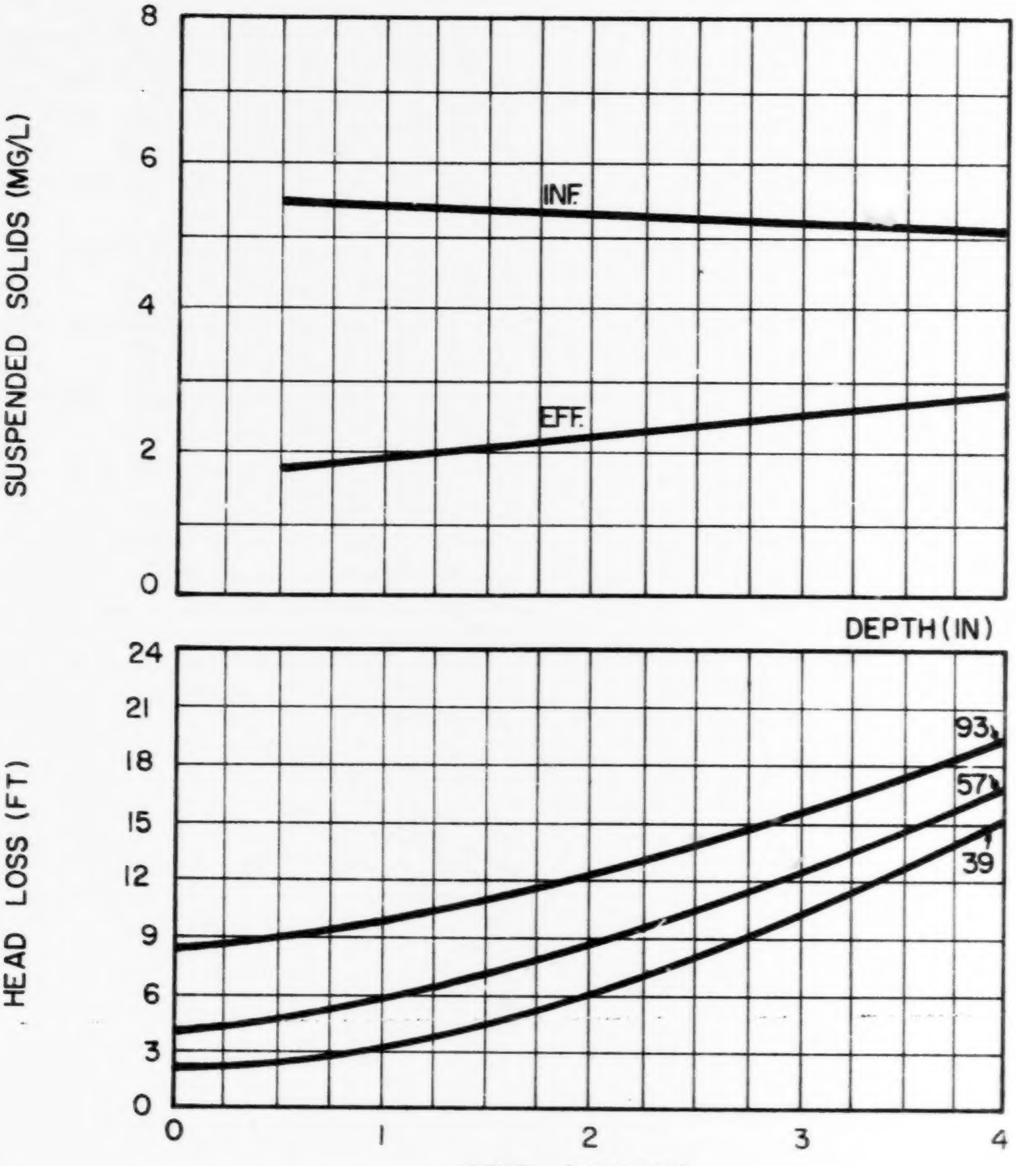
FILTER MEDIA 48 in. No. 1 ANTH./ 36 in No. 2050 SAND/18 in. GRAVEL

DATE 9/21/70 FLUX RATE 10 gpm/ft$^2$

RUN No. 7SEIV

SECONDARY EFFLUENT FILTRATION TEST

FIGURE D 8



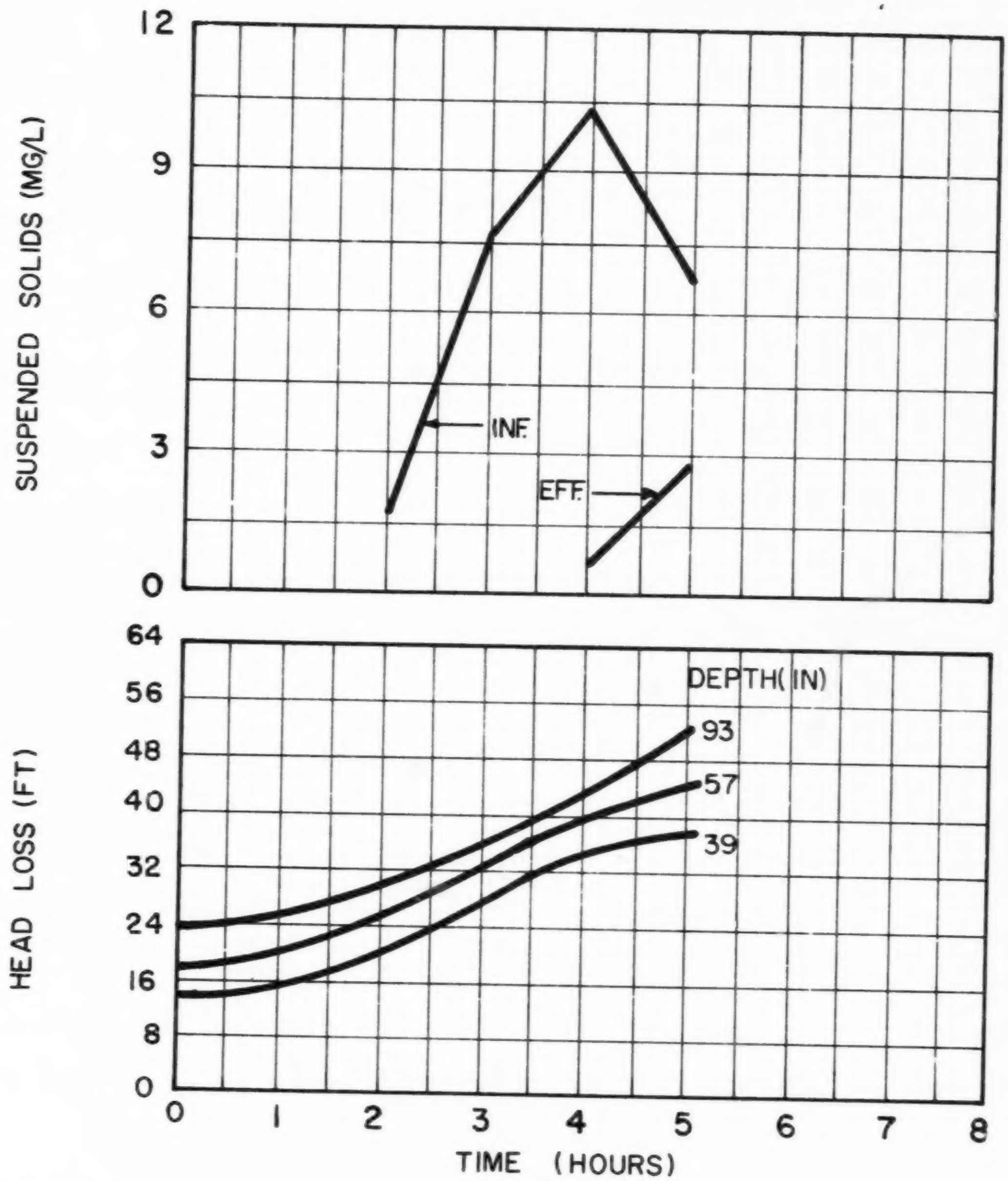
FILTER MEDIA 48 in. No. 1 ANTH./36 in No. 2050 SAND/18 in. GRAVEL

DATE 10/14/70 FLUX RATE 15 gpm/ft$^2$

RUN No. 8SEIV

SECONDARY EFFLUENT FILTRATION TEST

FIGURE D9



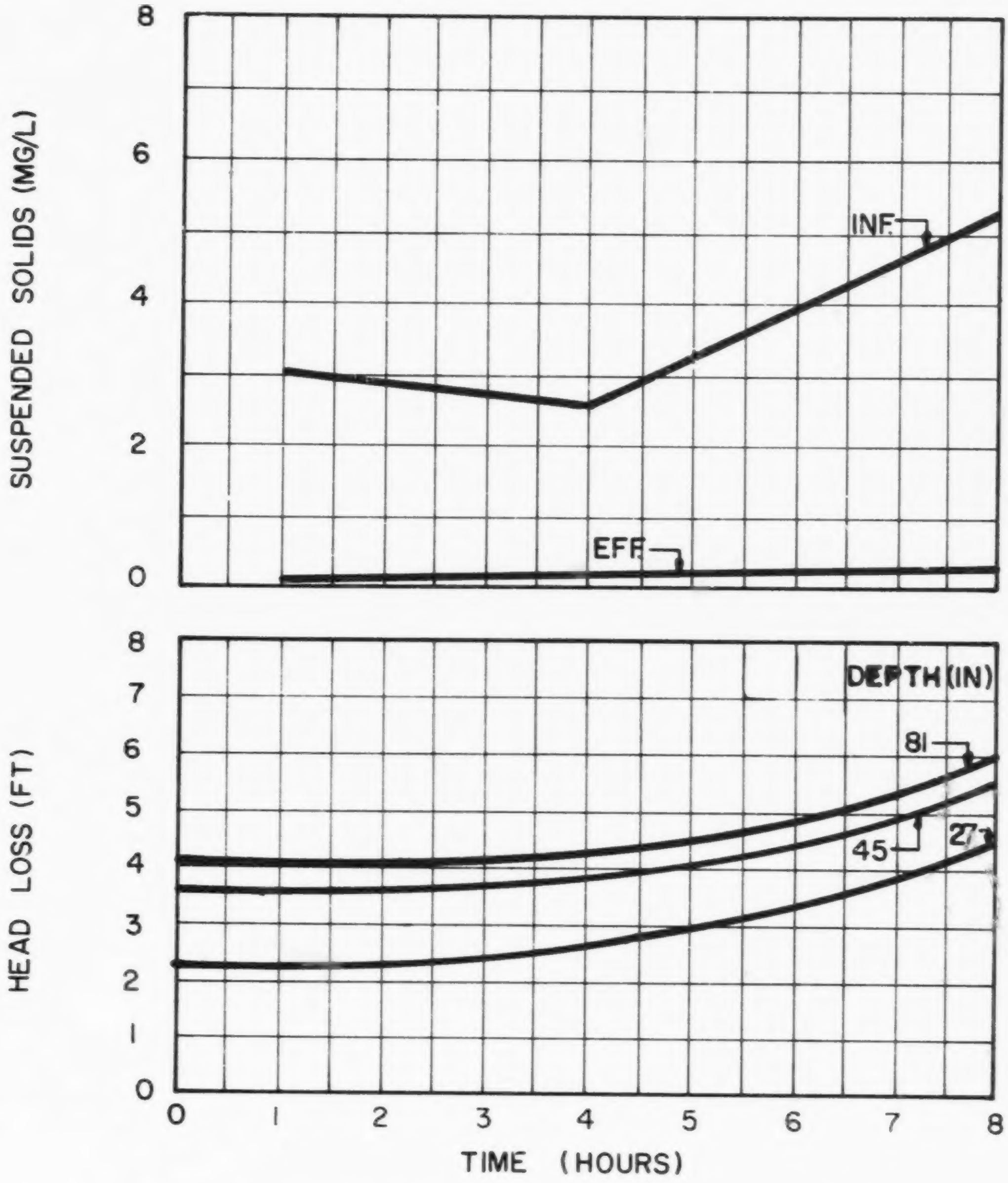
FILTER MEDIA 48 in. No. 1 ANTH./36 in No. 2050 SAND/18 in. GRAVEL

DATE 10/20/70 FLUX RATE 10 gpm/ft$^2$

RUN No. 9SEIV

## SECONDARY EFFLUENT FILTRATION TEST

FIGURE D 10



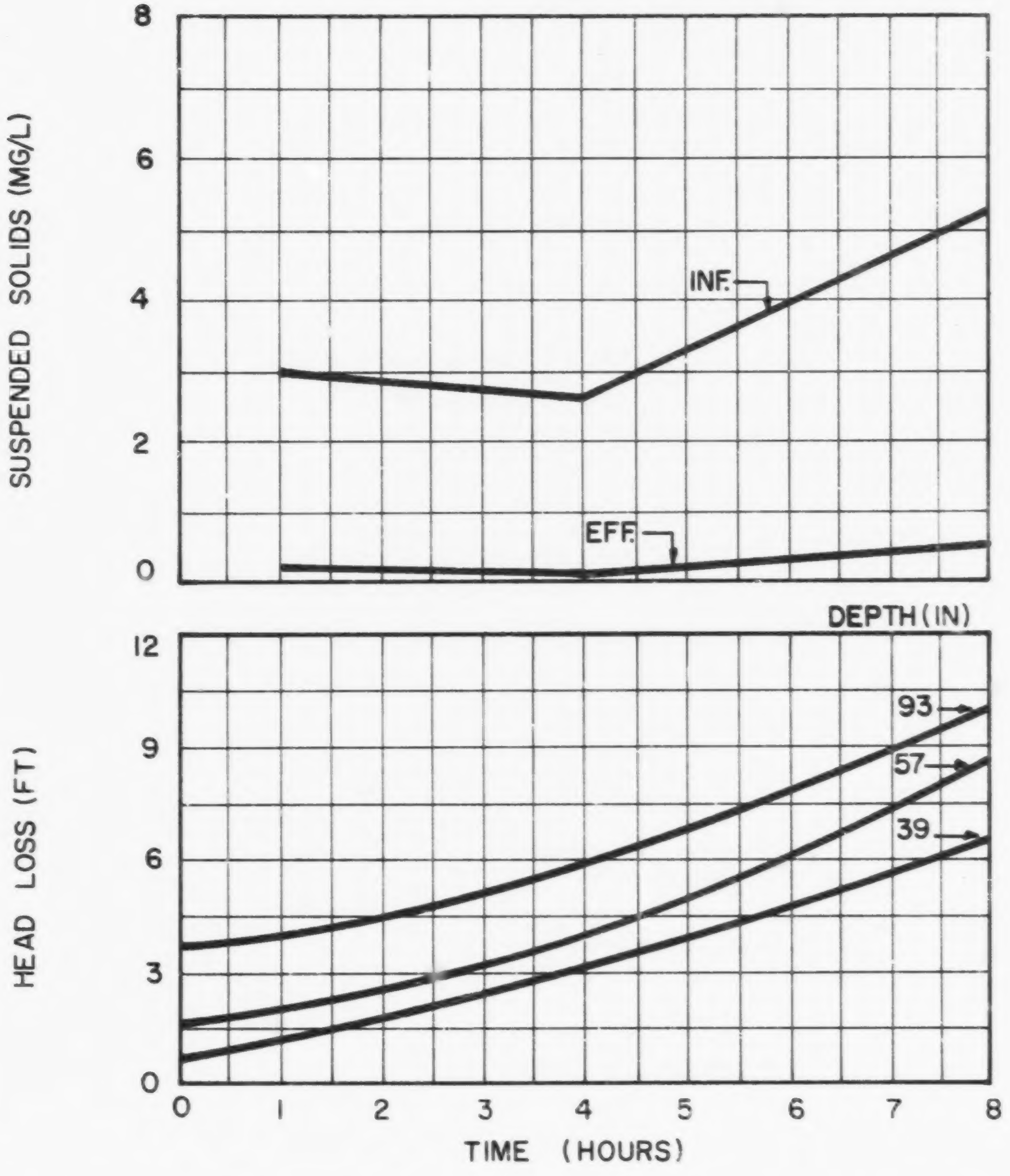
FILTER MEDIA 48 in. No. 1 1/2 ANTH./ 36 in No. 1220 SAND/18 in. GRAVEL

DATE 12/3/70 FLUX RATE 10 gpm/ft$^2$

RUN No. 10SEII

SECONDARY EFFLUENT FILTRATION TEST

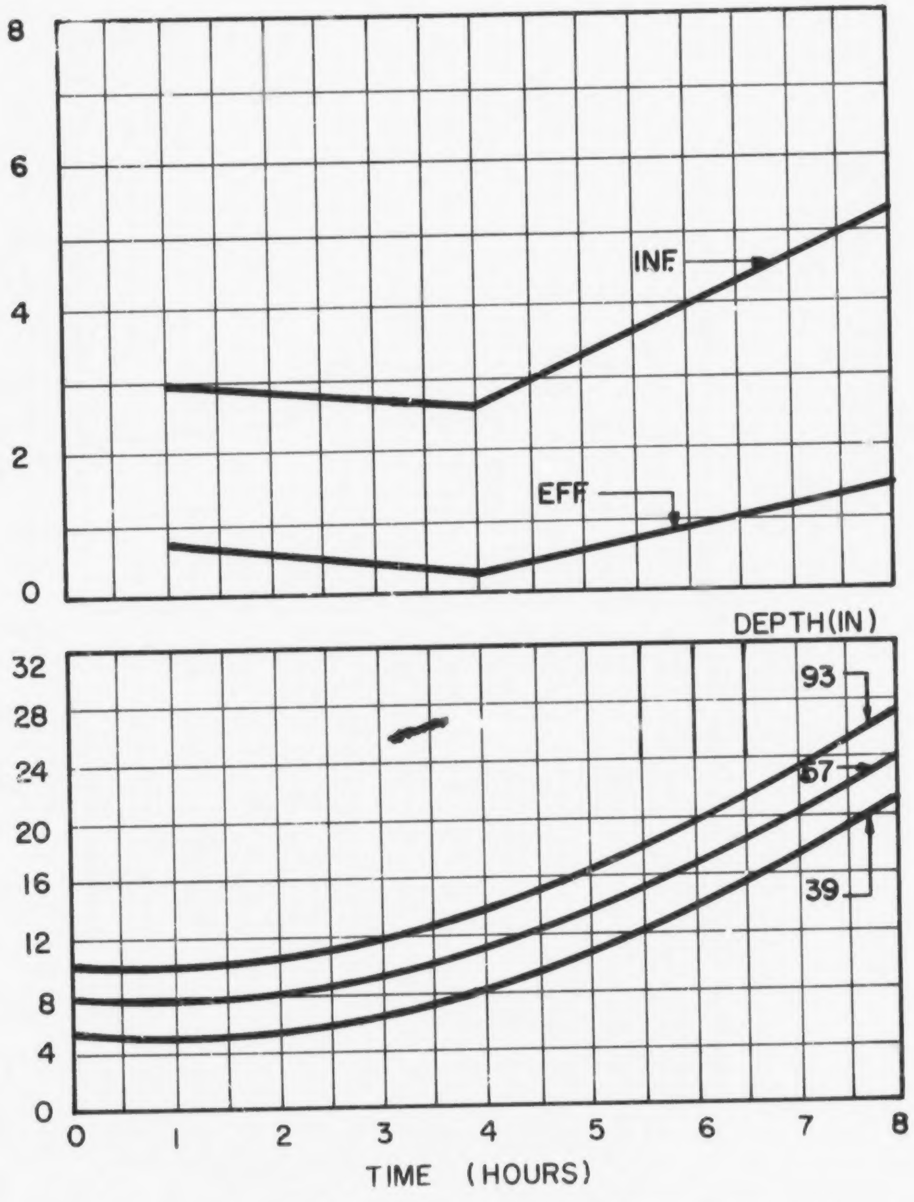
FIGURE D 11



FILTER MEDIA 48 in. No. 1 1/2 ANTH./ 36 in No. 1220 SAND/18 in. GRAVEL
DATE 12/3/70 FLUX RATE 15 gpm/ft$^2$
RUN No. 10SEIII

SECONDARY EFFLUENT FILTRATION TEST

FIGURE D 12



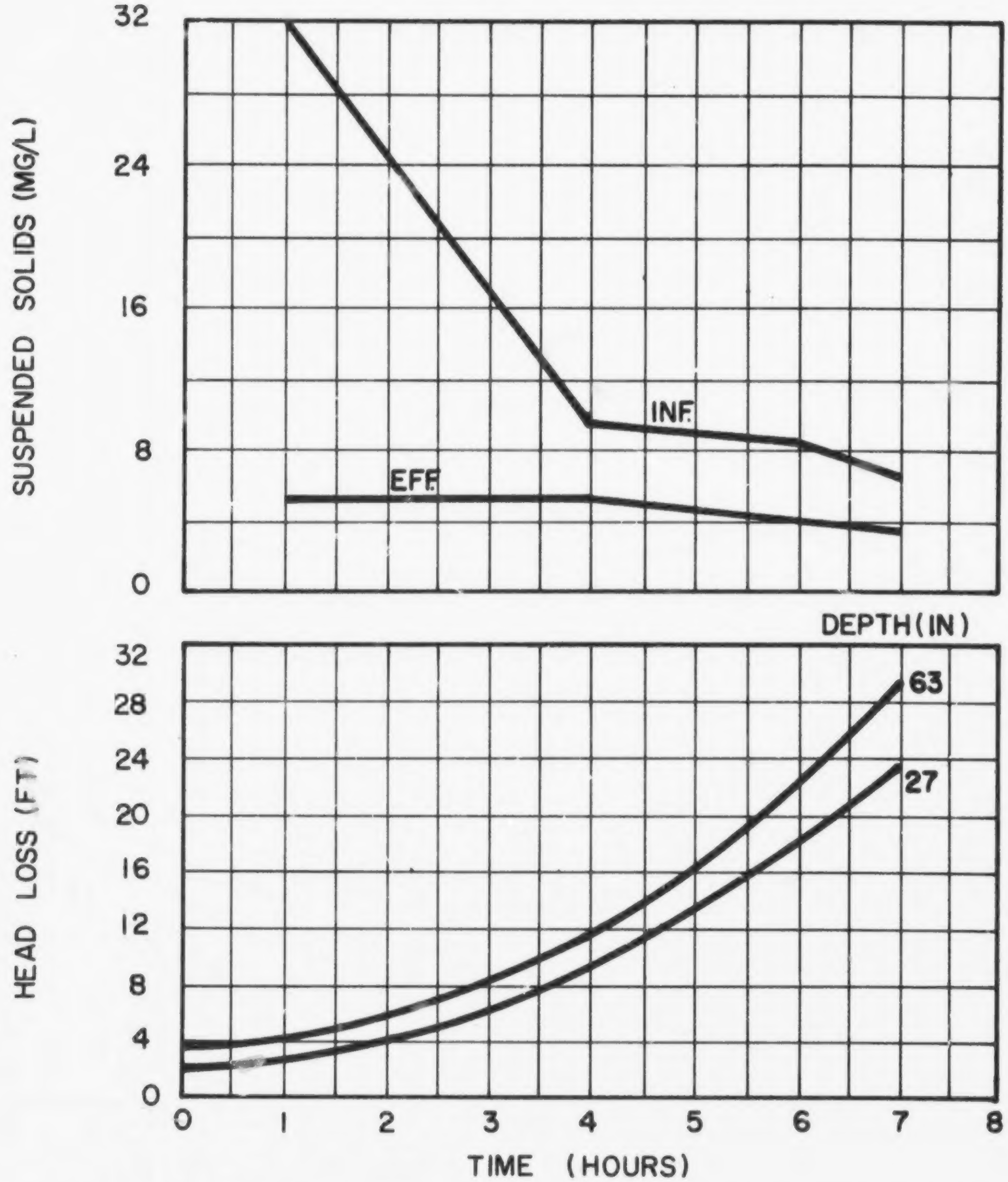
FILTER MEDIA 48 in. No 1 1/2 ANTH / 36 in No 1220 SAND / 18 in GRAVEL

DATE 12 / 3 / 70 FLUX RATE 30 gpm/ft$^2$

RUN No. 10SEIV

SECONDARY EFFLUENT FILTRATION TEST

FIGURE D 13



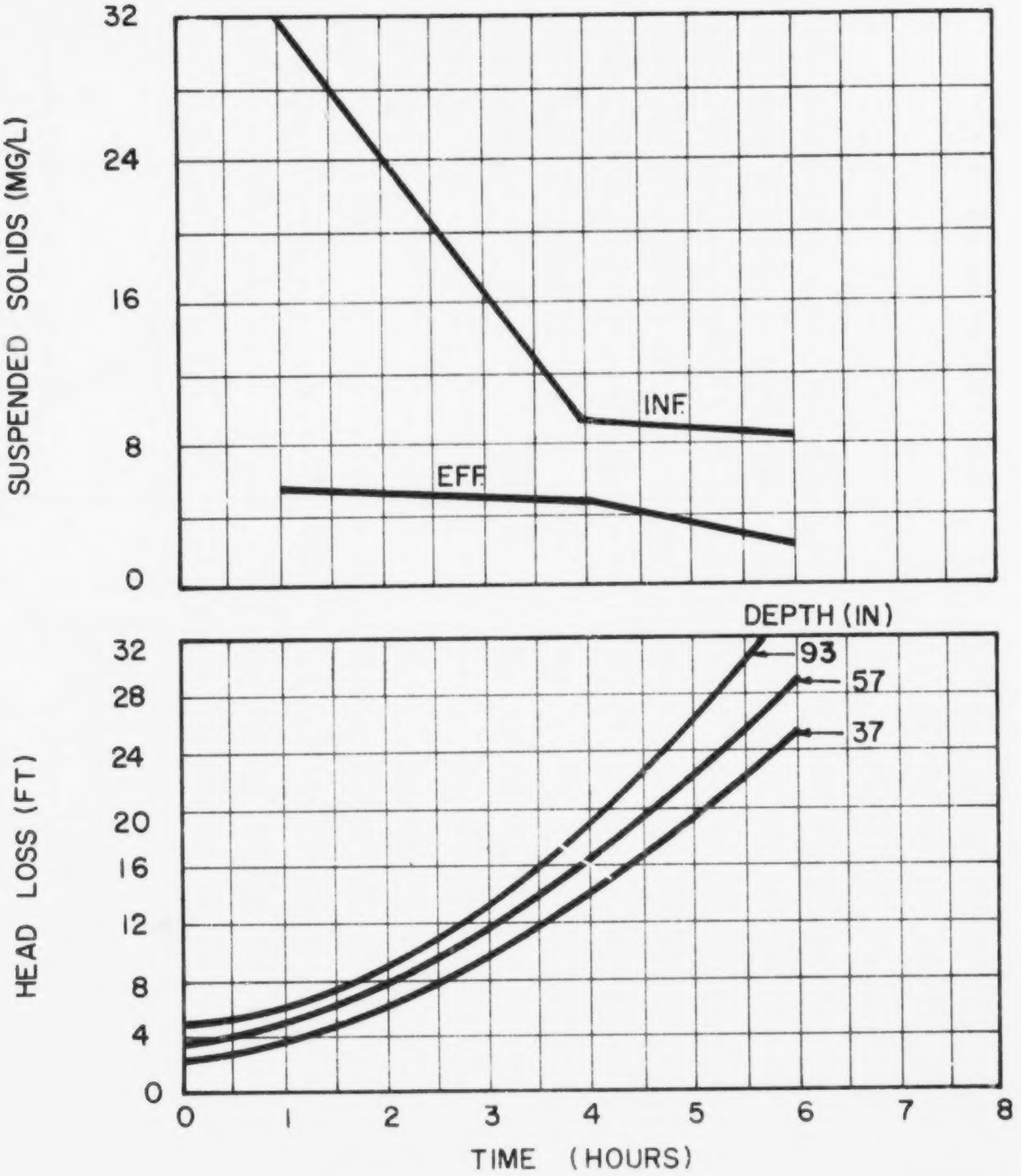
FILTER MEDIA 48 in. No. 1 1/2 ANTH./36 in No. 1220 SAND/18 in. GRAVEL

DATE 12/7/70 FLUX RATE 10 gpm/ft$^2$

RUN No. 11SE11

SECONDARY EFFLUENT FILTRATION TEST

FIGURE D 14



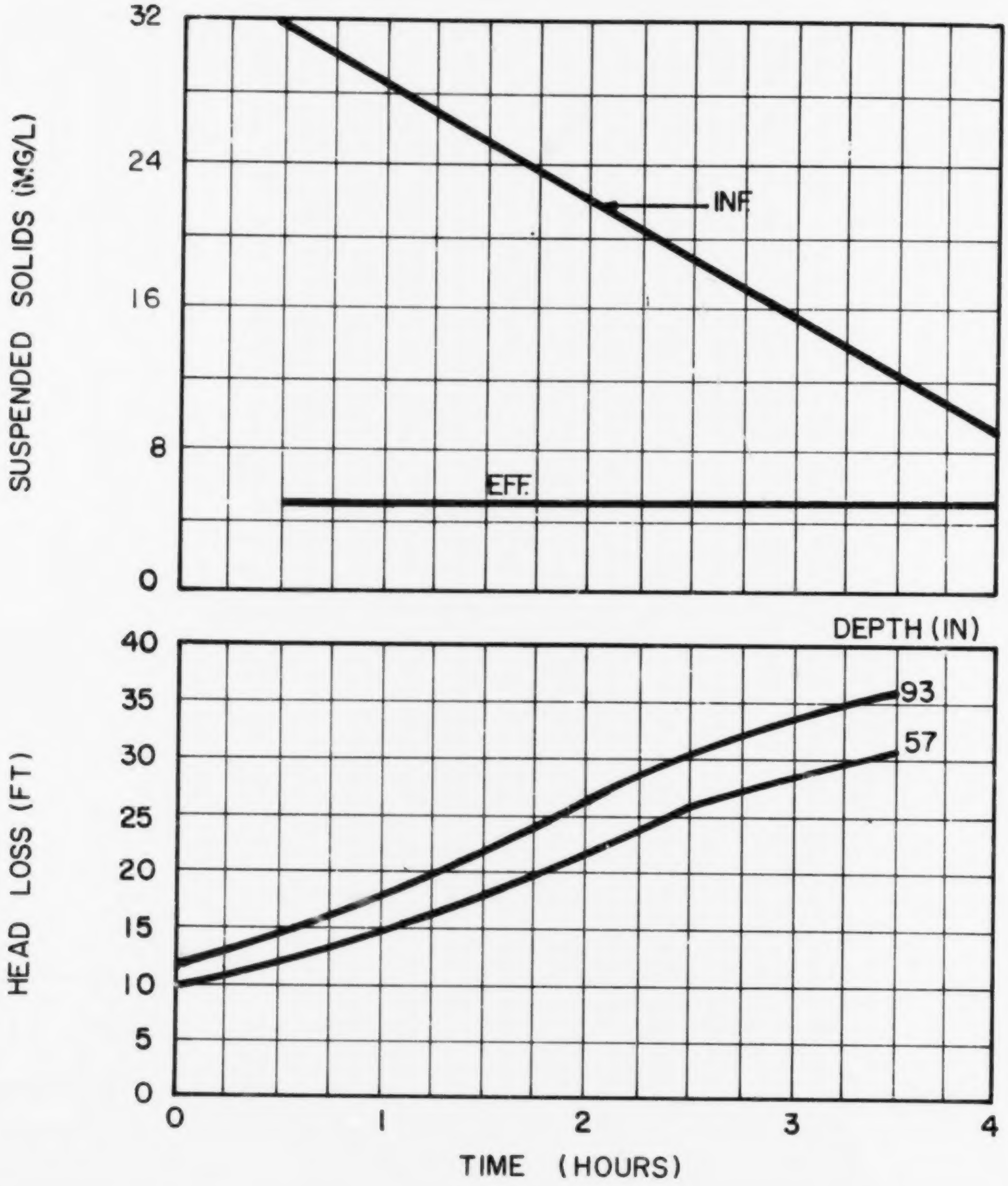
FILTER MEDIA 48 in. No. 1 1/2 ANTH./36 in No. 1220 SAND/18 in. GRAVEL

DATE 12/7/70 FLUX RATE 15 gpm/ft$^2$

RUN No. 11SEIII

**SECONDARY EFFLUENT FILTRATION TEST**

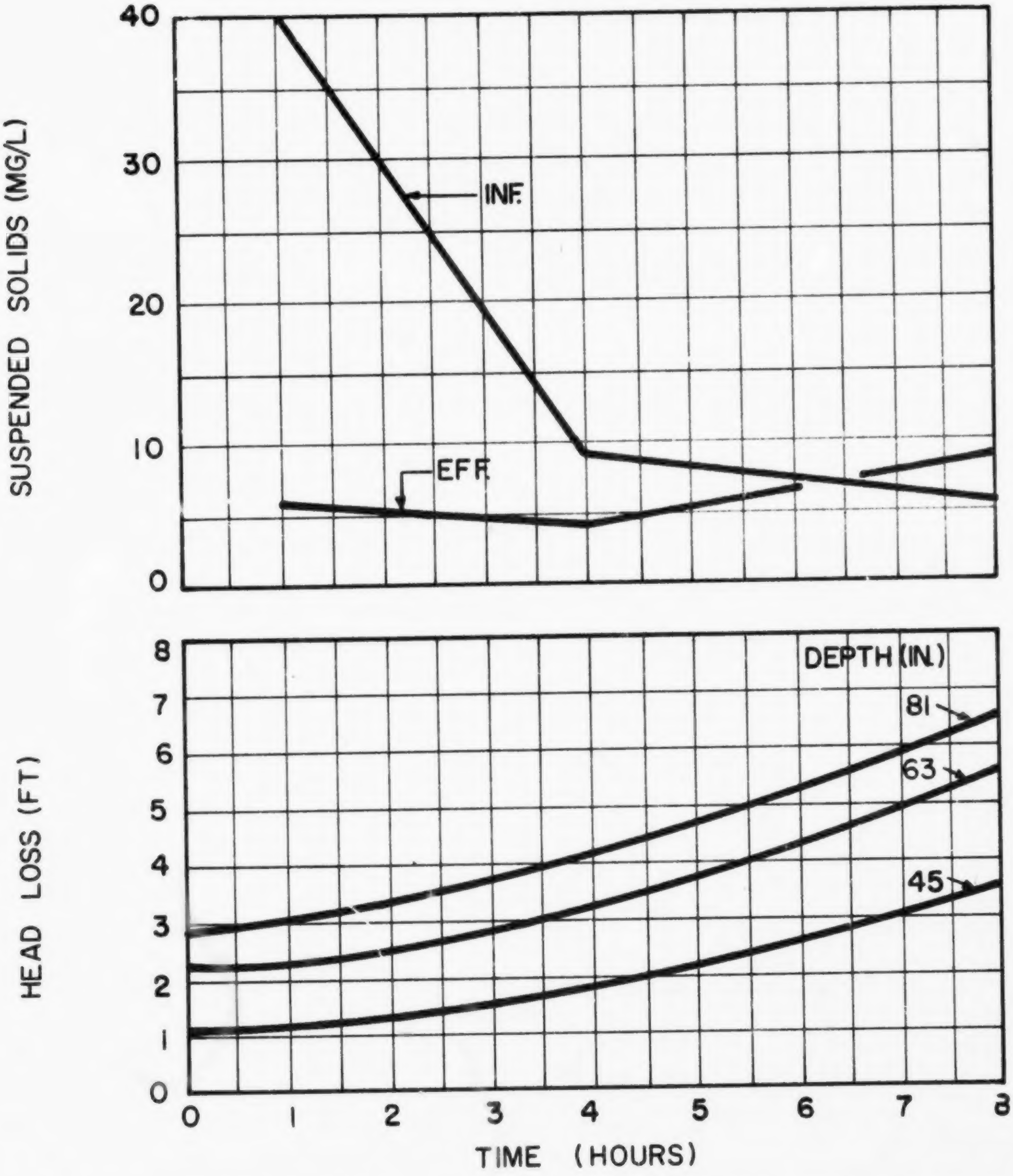
FIGURE D 15



FILTER MEDIA 48 in. No. 1 1/2 ANTH./36 in No. 220 SAND/18 in. GRAVEL
DATE 12/7/70 FLUX RATE 30 gpm/ft$^2$
RUN No. IISEIV

SECONDARY EFFLUENT FILTRATION TEST

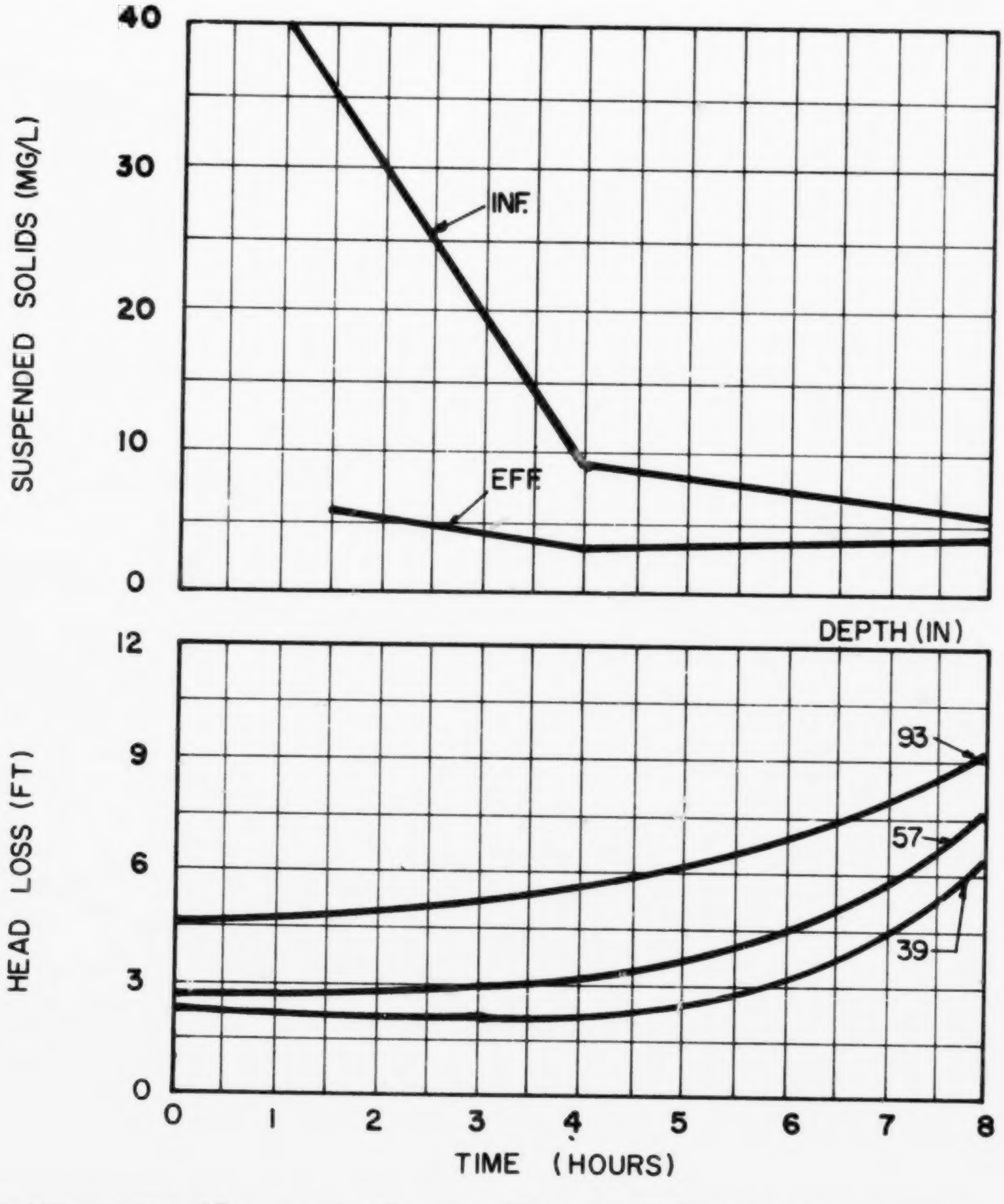
FIGURE D 16



FILTER MEDIA 48 in. No. 1 1/2 ANTH./ 36 in No. 1220 SAND/18 in. GRAVEL
DATE 12/8/70 FLUX RATE 10 gpm/ft²
RUN No. 12SEII

SECONDARY EFFLUENT FILTRATION TEST

FIGURE D17



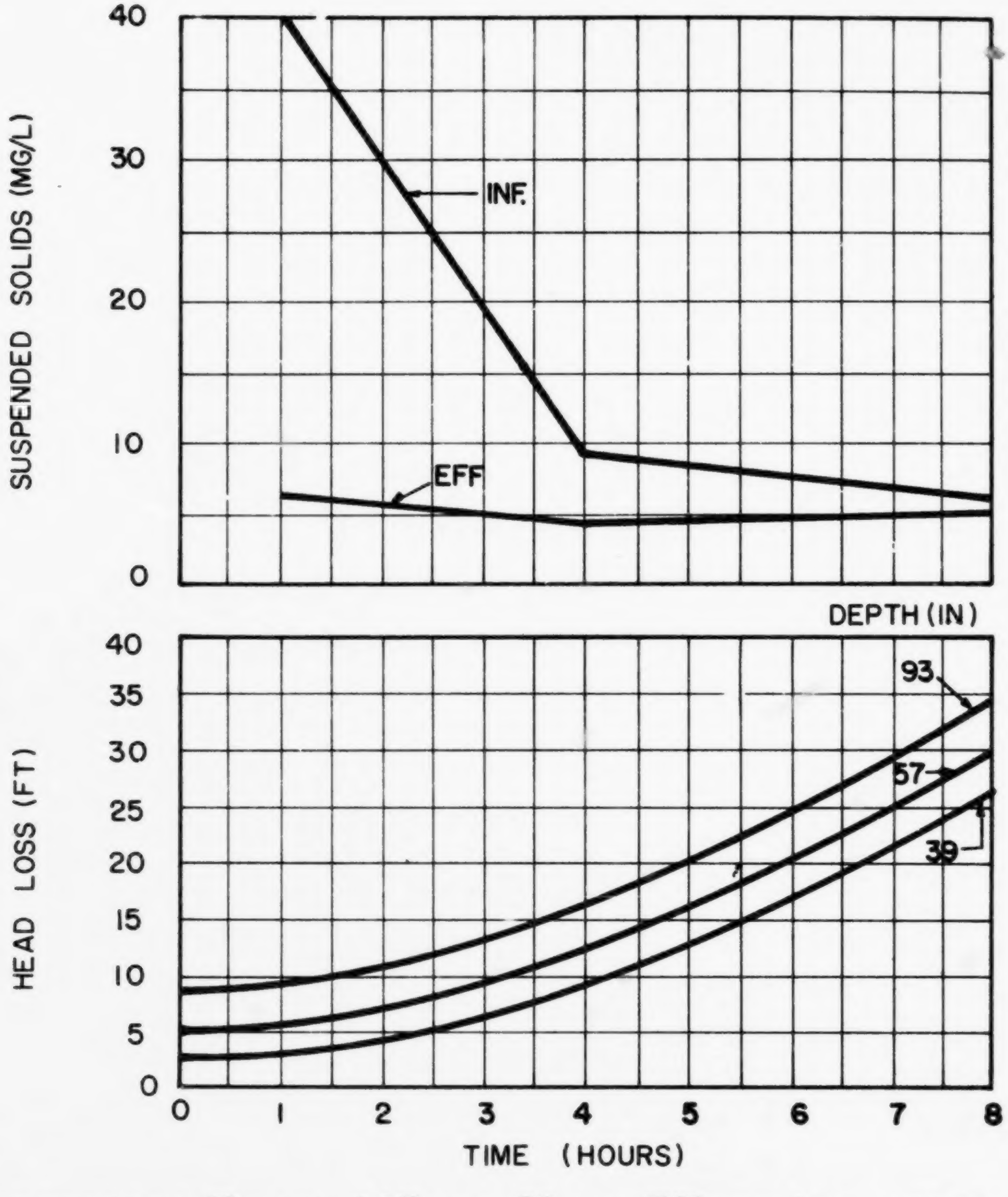
FILTER MEDIA 48 in. No. 1 1/2 ANTH./36 in No. 220 SAND/18 in. GRAVEL

DATE 12/8/70 FLUX RATE 15 gpm/ft$^2$

RUN No. 12 SE III

SECONDARY EFFLUENT FILTRATION TEST

FIGURE D 18



FILTER MEDIA 48 in. No. 1 1/2 ANTH./36 in No. 1220 SAND/18 in. GRAVEL

DATE 12/8/70 FLUX RATE 30 gpm/ft$^2$

RUN No. 12SEIV

SECONDARY EFFLUENT FILTRATION TEST

FIGURE D 19

# TABLE D-1

# HIGH - RATE FILTRATION OF SECONDARY EFFLUENT

| Run No. | Media | Flux Rate (gpm/ft$^2$) | Chemical Feed (mg/l) | Infl. Temp. °F | Suspended Solids<br>Inf. Avg. (mg/l) | Eff. Avg. (mg/l) | Ave. Removal % | Turbidity<br>Inf. Avg. (JTU) | Eff. Avg. (JTU) | Avg. Removal % | Total Organic Carbon<br>Inf Avg. (mg/l) | Eff. Avg. (mg/l) | Ave. Removal % | Total Phosphate<br>Inf Avg. (mg/l) | Eff. Avg. (mg/l) | Avg. Removal % | Terminal Head Loss (Ft) | Length of Run (Hrs.) | Total Vol. Filtered (Gals.) | Backwash<br>Total Volume (Gals.) | % Total Volume Filtered | Air Rate Scfm. |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 1SE-II | 48"#1 1/2A<br>36"#2050S | 24 | None | 77 | 10.1 | 4.5 | 55.4 | 42 | 36 | 14 | — | — | — | — | — | — | 24.7 | 12 | 3670 | 63.5** | 1.7 | 5 |
| 1SE-III | 48"#1 1/2A<br>36"#2050S | 16 | None | 77 | 10.1 | 3.9 | 61.4 | 42 | 31 | 26 | — | — | — | — | — | — | 18.0 | 12 | 2650 | 71.3** | 2.7 | 5 |
| 1SE-IV | 48"#1 1/2A<br>36"#2050S | 10 | None | 77 | 10.1 | 3.6 | 64.4 | 42 | 29 | 31 | — | — | — | — | — | — | 9.6 | 12 | 1530 | 63.5** | 4.2 | 8 |
| 2SE-IV | 48"#1 1/2A<br>36"#2050S | 10 | None | 78 | 6.2 | 2.2 | 64.5 | 21 | 16 | 24 | — | — | — | — | — | — | 11.7 | 14 | 1780 | 240** | 13.5 | 15 |
| 3SE-IV | 48"#1A<br>36"2050S | 10 | None | 71 | 4.3 | 0.27 | 93.7 | 23 | 18 | 22 | — | — | — | 3.2 | 2.5 | 21.9 | 11.7 | 12 | 1530 | — | — | — |
| 4SE-IV | 48"#1A<br>36"#2050S | 15 | None | 75 | 3.6 | 0.34 | 90.6 | 40 | 15 | 62 | — | — | — | 2.0 | 1.8 | 10.0 | 13.7 | 10 | 1910 | 74.2** | 3.9 | 10 |
| 5SE-IV | 48"#1A<br>36"#2050S | 30 | None | 75 | 4.1 | 2.2 | 47.6 | 18 | 12 | 33 | — | — | — | — | — | — | 25.1 | 5 | 1910 | 79.5** | 4.2 | 10 |
| 6SE-IV | 48"#2A<br>36"#2050S | 45 | None | — | UNABLE TO ATTAIN 45 GPM/FT$^2$ WITHIN RANGE OF PRESSURE GAUGES | | | | | | | | — | — | — | — | — | — | — | — | — | — |
| 7SE-IV* | 48"#2A<br>36"#2050S | 10 | 0.5 Poly<br>1.0 Alum. | 76 | 4.3 | 0.14 | 96.8 | 15 | 10 | 33 | — | — | — | 4.3 | 4.1 | 4.7 | 17.1 | 6 | 763 | 49.1*** | 6.4 | 7 |
| 8SE-IV | 48"#1A<br>36"#2050S | 15 | 0.5 Poly<br>1.0 Alum. | 78 | 5.3 | 2.3 | 66.0 | 13 | 8 | 38 | — | — | — | — | — | — | 18.4 | 4 | 763 | — | — | — |
| 9SE-IV | 48"#2A<br>36"#1220S | 10 | 1.0 Poly<br>5.0 Alum. | 66 | 9.0 | 1.6 | 82.3 | 36 | 25 | 31 | — | — | — | 1.24 | 1.1 | 11.3 | 31.7 | 5 | 636 | 82.6*** | 7.7 | 2.5 |
| 10SE-II | 48"#1 1/2A<br>36"#1220S | 10 | None | 55 | 5.5 | 0.32 | 94.2 | 18 | 8 | 56 | — | — | — | — | — | — | 5.4 | 8 | 1020 | — | — | — |
| 10SE-III | 48"#1 1/2A<br>36"#1220S | 15 | None | 55 | 5.5 | 0.25 | 95.4 | 18 | 11 | 39 | — | — | — | — | — | — | 10.1 | 8 | 1660 | — | — | — |
| 10SE-IV | 48"#1 1/2A<br>36"#1220S | 30 | None | 55 | 5.5 | 0.86 | 84.3 | 18 | 8 | 56 | — | — | — | — | — | — | 27.0 | 8 | 3660 | — | — | — |
| 11SE-II | 48"#1 1/2A<br>36"#1220S | 10 | 0.5 Poly<br>5.0 Alum. | 55 | 13.7 | 4.9 | 64.3 | 23 | 9 | 61 | — | — | — | — | — | — | 29.0 | 7.5 | 954 | — | — | — |
| 11SE-III | 48"#1 1/2A<br>36"#1220S | 15 | 0.5 Poly<br>5.0 Alum. | 55 | 13.7 | 4.6 | 66.4 | 23 | 14 | 39 | — | — | — | — | — | — | 40.0 | 6.5 | 1350 | — | — | — |
| 11SE-IV | 48"#1 1/2A<br>36"#1220S | 30 | 0.5 Poly<br>5.0 Alum. | 55 | 13.7 | 5.4 | 60.6 | 23 | 11 | 52 | — | — | — | — | — | — | 35.5 | 4 | 1530 | — | — | — |
| 12SE-II | 48"#1 1/2A<br>36"#1220S | 10 | 1.0 Poly<br>5.0Alum. | 57 | 18.4 | 6.6 | 64.1 | 31 | 21 | 32 | 10 | 8 | 20 | — | — | — | 6.5 | 8 | 1020 | — | — | — |
| 12SE-III | 48"#1 1/2A<br>36"#1220S | 15 | 1.0 Poly<br>5.0 Alum. | 57 | 18.4 | 4.9 | 73.4 | 31 | 17 | 45 | 10 | 8 | 20 | — | — | — | 9.0 | 8 | 1660 | — | — | — |
| 12SE-IV | 48"#1 1/2A<br>36"#1220S | 30 | 1.0 Poly<br>5.0 Alum. | 57 | 18.4 | 5.3 | 71.2 | 31 | 14 | 55 | 10 | 7 | 30 | — | — | — | 33.5 | 8 | 3060 | — | — | — |

* Calculations Based on Composite Samples

** Calculations Based on Flow Rate Times Time of Backwash

*** Calculations Based on Water Depth in Backwash Tank

# APPENDIX E

## THE EFFECT OF PUMPING ON PARTICLE SIZE IN OVERFLOWS

Tables E-1 through E-3 show the effect of pumping on particle size, as determined by particle counter analysis. These analyses were performed by the AWT Research Laboratory (Cincinnati) on samples taken before and after the pilot plant influent pump, that is, at the Junction Chamber, and at the Pump Discharge.

The data indicate an increase in the number of smaller particles after pumping. For example, for particle sizes equal to or larger than 40.173 microns, the number of particles per milliliter in the Junction Chamber samples were approximately forty-five percent greater than in the Pump Discharge samples.

Table E-l

## COMBINED SEWER OVERFLOW SUSPENDED SOLIDS
## PARTICLE COUNTER RUN No. 1*

| Particle Diameter (Microns) | Junction Chamber N/ML | Junction Chamber % Cumul. | Pump Discharge N/ML | Pump Discharge % Cumul. |
|---|---|---|---|---|
| 60.995 | - | - | 1. | |
| | | | | 0.0 |
| 54.523 | 1. | | 2. | |
| | | 0.7 | | 0.2 |
| 45.987 | 12. | | 6. | |
| | | 2.7 | | 1.0 |
| 40.173 | 60. | | 24. | |
| | | 4.6 | | 1.9 |
| 36.499 | 123. | | 55. | |
| | | 8.5 | | 4.3 |
| 31.885 | 306. | | 174. | |
| | | 15.4 | | 9.7 |
| 28.311 | 779. | | 563. | |
| | | 21.3 | | 14.9 |
| 25.307 | 1356. | | 1099. | |
| | | 30.4 | | 23.8 |
| 21.345 | 2697. | | 2475. | |
| | | 38.6 | | 31.6 |
| 18.646 | 4616. | | 4393. | |
| | | 43.5 | | 36.7 |
| 16.941 | 6276. | | 6183. | |
| | | 50.1 | | 43.5 |
| 14.800 | 9346. | | 9506. | |
| | | 60.2 | | 53.6 |
| 13.140 | 16318. | | 16822. | |
| | | 65.4 | | 60.1 |
| 11.746 | 21432 | | 23498. | |
| | | 72.4 | | 68.7 |
| 9.907 | 31763 | | 36806. | |
| | | 77.1 | | 74.6 |
| 8.655 | 42786 | | 51361. | |
| | | 79.9 | | 77.9 |

* Sampling Time: 12/3/70 15:30

Table E-1 (Continued)

| Particle Diameter (Microns) | Junction Chamber | | Pump Discharge | |
|---|---|---|---|---|
| | N/ML | % Cumul. | N/ML | % Cumul. |
| 7.863 | 52116. | | 62857. | |
| | | 82.9 | | 81.5 |
| 6.869 | 66246. | | 80786. | |
| | | 86.4 | | 85.9 |
| 6.099 | 90582. | | 112093. | |
| | | 89.1 | | 88.9 |
| 5.452 | 116270. | | 142806. | |
| | | 92.8 | | 93.0 |
| 4.598 | 171705. | | 207240. | |
| | | 95.8 | | 96.2 |
| 4.017 | 242127. | | 284525. | |
| | | 98.0 | | 98.3 |
| 3.649 | 313267. | | 358348. | |
| | | 100.0 | | 100.0 |
| 3.188 | 406437. | | 440158. | |

REMARKS: N/ML: Number of particles equal to or greater than given particle diameter.

% Cumul: Cumulative percentage by volume for each particle diameter range (Cumulative by weight assuming all particles have the same density).

Table E-2

## COMBINED SEWER OVERFLOW SUSPENDED SOLIDS
## PARTICLE COUNTER RUN No. 2*

| Particle Diameter (Microns) | Junction Chamber | | Pump Discharge | |
|---|---|---|---|---|
| | N/ML | % Cumul. | N/ML | % Cumul. |
| 60.995 | - | - | 1. | |
| | | - | | 0.0 |
| 54.523 | 2. | | 1. | |
| | | 0.6 | | 0.5 |
| 45.987 | 17. | | 9. | |
| | | 2.4 | | 2.7 |
| 40.173 | 90. | | 62. | |
| | | 4.6 | | 5.1 |
| 36.499 | 215. | | 146. | |
| | | 8.6 | | 9.4 |
| 31.885 | 535. | | 350. | |
| | | 16.5 | | 17.3 |
| 28.311 | 1461. | | 912. | |
| | | 24.9 | | 24.7 |
| 25.307 | 2840. | | 1652. | |
| | | 41.3 | | 38.2 |
| 21.345 | 6928. | | 3683. | |
| | | 56.2 | | 50.1 |
| 18.646 | 12851. | | 6529. | |
| | | 65.2 | | 57.3 |
| 16.941 | 17962. | | 9012. | |
| | | 74.8 | | 65.4 |
| 14.800 | 25628. | | 12875. | |
| | | 83.5 | | 74.1 |
| 13.140 | 35796. | | 19086. | |
| | | 87.3 | | 78.7 |
| 11.746 | 41996. | | 23666. | |
| | | 90.4 | | 83.3 |
| 9.907 | 49844. | | 30565. | |
| | | 91.8 | | 85.9 |
| 8.655 | 55433. | | 36895. | |
| | | 92.6 | | 87.5 |

* Sampling Time: 12/3/70 17:30

Table E-2 (Continued)

| Particle Diameter (Microns) | Junction Chamber N/ML | Junction Chamber % Cumul. | Pump Discharge N/ML | Pump Discharge % Cumul. |
|---|---|---|---|---|
| 7.863 | 60130. | | 42130. | |
| | | 93.4 | | 89.1 |
| 6.869 | 66331. | | 50045. | |
| | | 95.4 | | 91.6 |
| 6.099 | 89663. | | 67860. | |
| | | 96.4 | | 93.2 |
| 5.452 | 106291. | | 84087. | |
| | | 97.9 | | 95.7 |
| 4.598 | 143522. | | 120565. | |
| | | 98.9 | | 97.6 |
| 4.017 | 184510. | | 166554. | |
| | | 99.6 | | 98.9 |
| 3.649 | 220173. | | 210269. | |
| | | 100.0 | | 100.0 |
| 3.188 | 249837. | | 262880. | |

Table E-3

## COMBINED SEWER OVERFLOW SUSPENDED SOLIDS
## PARTICLE COUNTER RUN No. 3*

| Particle Diameter (Microns) | Junction Chamber N/ML | Junction Chamber % Cumul. | Pump Discharge N/ML | Pump Discharge % Cumul. |
|---|---|---|---|---|
| 60.995 | - | | - | |
| | | - | | - |
| 54.523 | 1. | | 1. | |
| | | 0.5 | | 0.3 |
| 45.987 | 7. | | 5. | |
| | | 1.9 | | 1.0 |
| 40.173 | 36. | | 20. | |
| | | 3.0 | | 2.1 |
| 36.499 | 68. | | 51. | |
| | | 5.3 | | 4.1 |
| 31.885 | 159. | | 130. | |
| | | 9.4 | | 7.7 |
| 28.311 | 399. | | 338. | |
| | | 13.0 | | 10.6 |
| 25.307 | 695. | | 580. | |
| | | 18.0 | | 15.2 |
| 21.345 | 1329. | | 1158. | |
| | | 22.1 | | 19.3 |
| 18.646 | 2130. | | 1972. | |
| | | 24.8 | | 22.0 |
| 16.941 | 2903. | | 2728. | |
| | | 28.5 | | 25.6 |
| 14.800 | 4413. | | 4151. | |
| | | 37.5 | | 32.2 |
| 13.140 | 9681. | | 8031. | |
| | | 47.1 | | 38.5 |
| 11.746 | 17609. | | 13280. | |
| | | 65.4 | | 52.3 |
| 9.907 | 40509. | | 30406. | |
| | | 78.5 | | 66.0 |
| 8.655 | 66667. | | 57688. | |
| | | 85.2 | | 74.7 |

* Sampling Time: 12/3/70 20:30

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Table E-3 (Continued)

| Particle Diameter (Microns) | Junction Chamber N/ML | Junction Chamber % Cumul. | Pump Discharge N/ML | Pump Discharge % Cumul. |
|---|---|---|---|---|
| 7.863 | 85845. | | 82343. | |
| | | 90.6 | | 83.7 |
| 6.869 | 107328. | | 118032. | |
| | | 94.3 | | 90.2 |
| 6.099 | 128822. | | 156225. | |
| | | 96.6 | | 94.5 |
| 5.452 | 147593. | | 191797 | |
| | | 98.4 | | 97.8 |
| 4.598 | 170150. | | 232515. | |
| | | 99.1 | | 99.0 |
| 4.017 | 185587. | | 257370. | |
| | | 99.6 | | 99.7 |
| 3.649 | 199965. | | 276875. | |
| | | 100.0 | | 100.0 |
| 3.188 | 212483. | | 285497. | |

1 *Accession Number*

**W**

2 *Subject Field & Group*

**SELECTED WATER RESOURCES ABSTRACTS**
**INPUT TRANSACTION FORM**

5 *Organization*

Hydrotechnic Corporation, Consulting Engineers
641 Lexington Avenue, New York, New York 10022

6 *Title*

High Rate Filtration of Combined Sewer Overflows

10 *Author(s)*

Ross Nebolsine
Patrick J. Harvey
Chi-Yuan Fan

16 *Project Designation*

EPA, ORM Project #11023EYI, Contract #14-12-858

21 *Note*

22 *Citation*

Water Pollution Control Research Series 11023EYI 04/72

23 *Descriptors (Starred First)*

*Combined Sewer Overflow, *Deep bed, dual media, high rate filtration, *Drum screen, Anthracite, Sand, Suspended Solids, Biochemical Oxygen Demand, Chemical Oxygen Demand, Coliforms, Precipitation, Urban Runoff, Activated Sludge Plant Effluent, Cost Estimates.

25 *Identifiers (Starred First)*

*Combined Sewers, Cleveland, Ohio

27 *Abstract*

Pilot plant studies were conducted at Cleveland's Southerly Wastewater Treatment Plant in 1970 and 1971, to develop and demonstrate the capabilities of the deep bed, dual media, high rate filtrate treatment process for storm caused combined sewer overflows.

The treatment system is comprised of a drum screen with a 40 mesh screening element (420 microns opening) followed by a deep bed, dual media, high rate filter of five feet of No. 3 anthracite (effective size 4 mm) over three feet of No. 612 Sand (effective size 2 mm). The results show suspended solids removals of 93 percent, with polyelectrolyte addition, at a filtration rate of 24 gpm/sq ft at an average influent suspended solids of 411 mg/l. Reductions in biochemical oxygen demand averaged 65 percent.

Capital costs (ENR=1470) for a high rate filtration plant are about $23,000 per mgd. Total annual treatment costs, including capital and operating charges, range from approx. $90,000 per yr for a 25 MGD plant to approx. $390,000 for a 200 MGD treatment facility.

Principal advantages of the proposed system are: high treatment efficiencies, automated operation, and limited space requirements as compared with alternate flotation or sedimentation systems.

This report was submitted in fulfillment of Project #11023EYI (Contract 14-12-858) under the sponsorship of the Office of Research and Monitoring, USEPA.

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